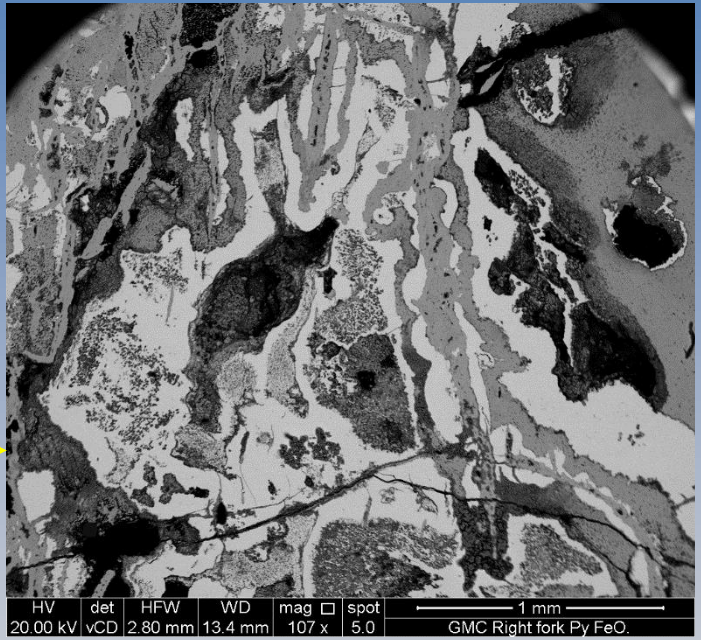
# 2. Stream sediment sampling methods

Regional surveys typically separate two different fractions of the bulk sediment:

| Heavy Mineral Concentrates HMC | Sediment fines |
| --- | --- |
| 150-2000 µm | <150 µm |
| Exploit the fact that metallic minerals have relatively high densities | Sieving removes much of the quartz and feldspars, concentrates fine material carrying metals |

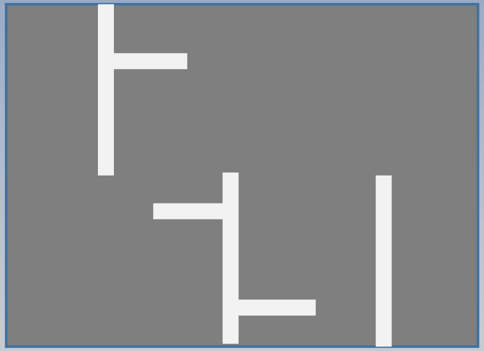
‘Fines’ make more sense if you appreciate HOW the metals may be present…

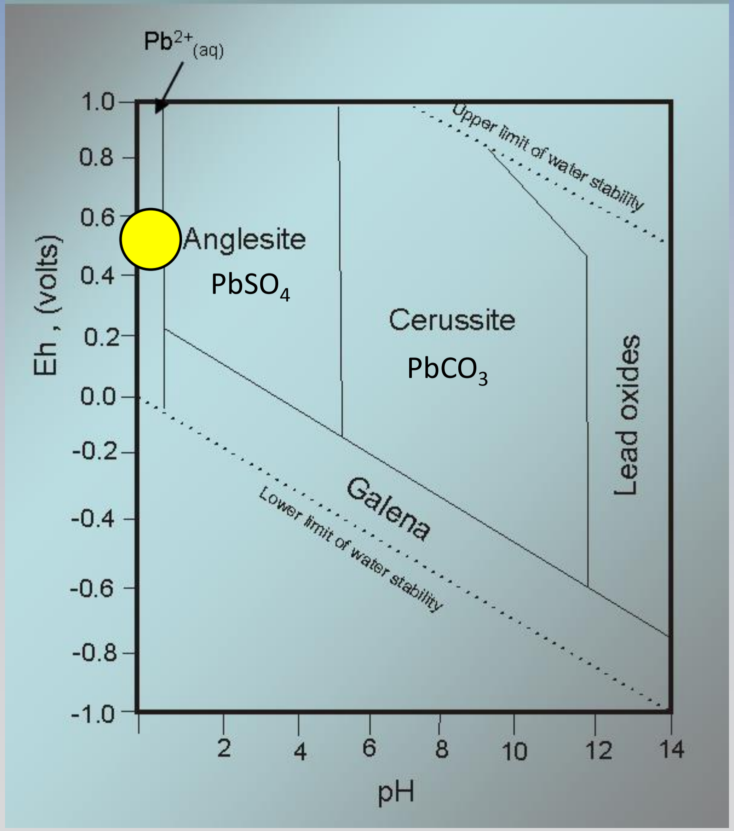
# Decomposition of metal sulphide minerals




Decomposition is 'within' the mineral

For galena, exploits cleavage planes





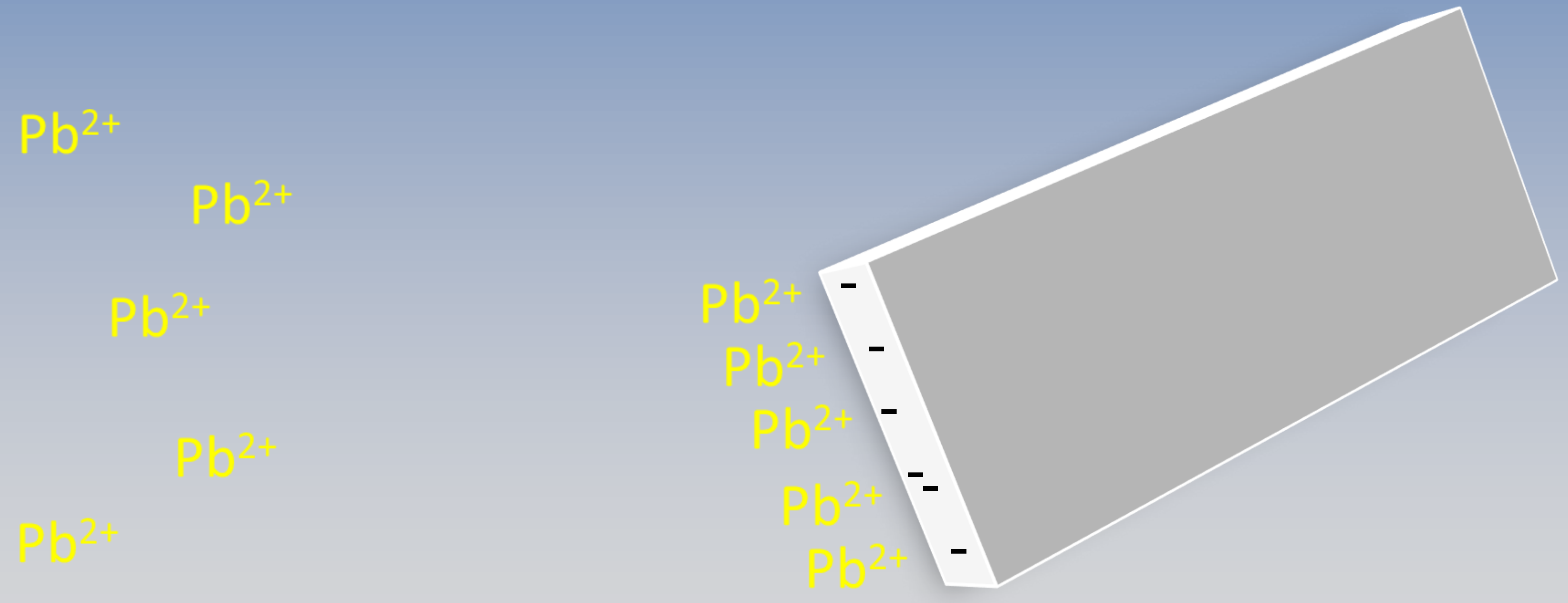

$PbS \rightarrow Pb^{2+} + S^{2-}$

# The fate of $Pb^{2+}$ ions

Either forms cerussite or anglesite *in situ*

$PbCO_3$ $PbSO_4$

Or the metal ions migrate in porewater, and are adsorbed onto **clay minerals**:



# Heavy minerals

- Definitions vary: usually minerals significantly denser than quartz (SG 2.65), though this excludes some minerals often regarded as 'heavy' – apatite, epidote, spodumene, tourmaline.
- Usually refers to weathering-resistant oxide and silicate minerals, though sulphides may survive in glacial till and low-redox contexts.
- Many studies published on using heavy minerals in regional surveys and mineral exploration – mostly in stream sediments, but also in glacial tills, especially in Scandinavia and Canada. Examples:
  - Peuraniemi, Vesa. 1990. 'Heavy minerals in glacial material', chapter 10 in 'Glacial Indicator Tracing' edited by R. Kujansuu & M. Saarnisto (Balkema)
  - Mange, Maria A. and Wright, David T. (editors) 2007. 'Heavy Minerals in Use'. Developments in Sedimentology 58 (Elsevier)

# Heavy minerals as indicators of location and styles of auriferous mineralization

HMC mineralogy can inform the exploration geologist on the **distance to source** and the **style** of **associated mineralization** – IF the gold and other heavy minerals are genetically related, i.e. derived from the same mineralized bedrock.

**Caution !! – placer gold sourced from fairly local bedrock may co-exist with other heavy minerals transported from distant sources !!**

# Heavy minerals as indicators of location and styles of auriferous mineralization

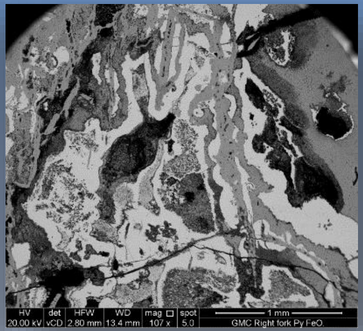
- Association of placer gold with mechanically weak minerals that are transported **relatively short distances**, such as barite and cinnabar, can indicate the presence of **proximal** bedrock mineralization.
- Similarly, the presence of sulphide and sulpharsenide minerals in a HMC indicate **proximal** bedrock mineralization as they rapidly oxidise in fluvial environments.
- Such minerals may be preserved under reducing conditions in glacial sediments and are more commonly found in HMC from till samples.
- Bedrock geology of catchments may be inferred from abundance of minerals indicative of particular **lithological associations** e.g.
  - chromite » mafic–ultramafic
  - cassiterite » granitic

# Influences on alluvial persistence

characteristics of good indicator minerals

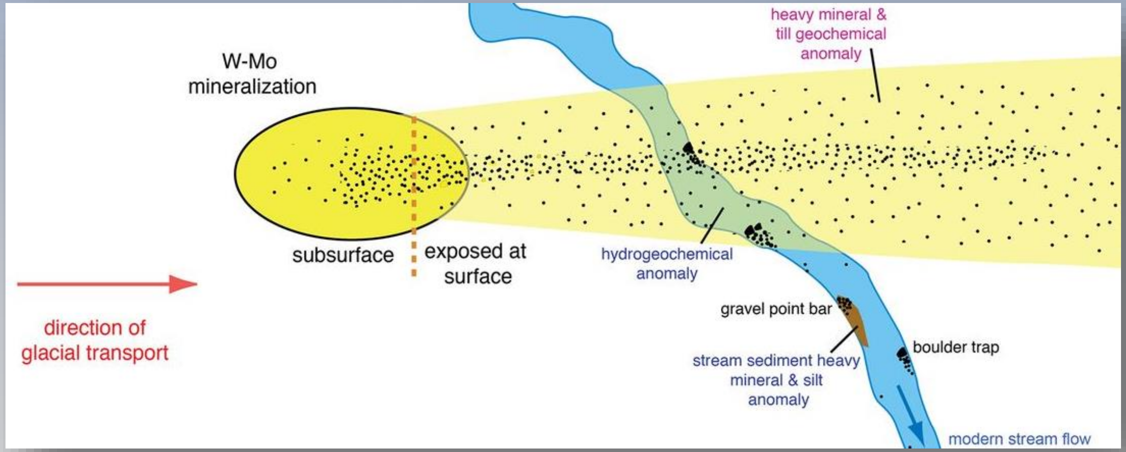
## Mineral characteristics

- hardness OR ductility (e.g. gold)
- tendency to cleave (e.g. galena)
- chemical stability vs. formation of secondary minerals



## Topography and bedform

- steepness of gradient
- bedform type e.g. bedrock or surficial deposits
- presence of ‘traps’ e.g. jagged bedrock, moss

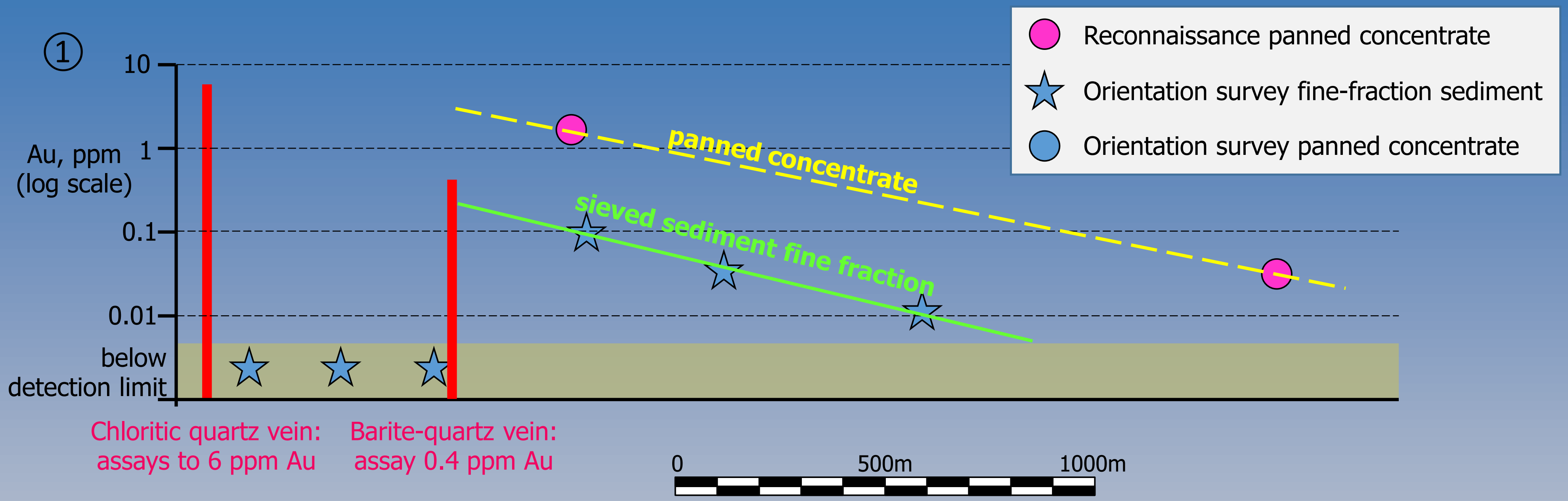


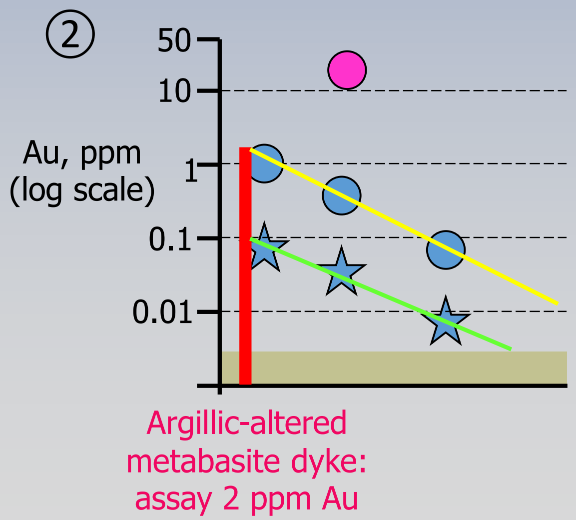

McClenaghan et al. (2017) https://doi.org/10.1144/geochem2015-396

## Dilution

- confluence with similar-sized or larger streams

# Orientation study: gold persistence in Donegal rivers




- In fine sediment, detectable gold persists for 0.5–1km downstream
- In panned concentrates, gold persists for 1–2km downstream
- Method decision: collect panned concentrate samples at 0.5 km spacing

Moles & Schaffalitzky (1992) Gold exploration methodologies and target definition in the Donegal Dalradian. In: Bowden, A.A. et al. 'The Irish Minerals Industry 1980-1990'. Irish Association for Economic Geology, Dublin. Pp.119-134.

# Advantages of collecting HMCs in reconnaissance gold exploration (as opposed to sampling ‘fines’)

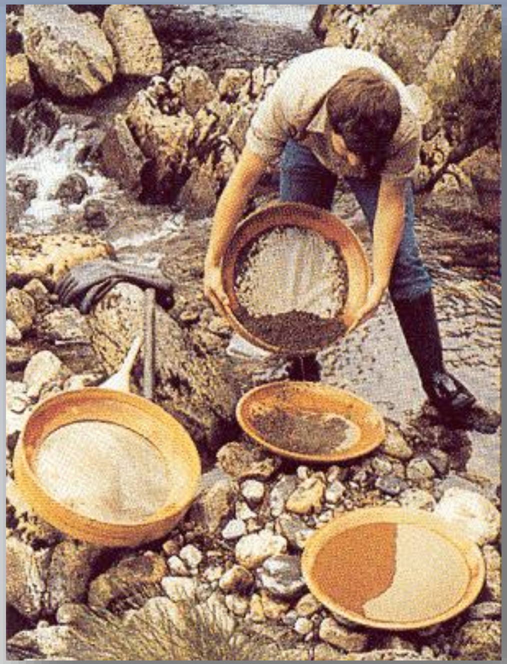
- **Enables rapid coverage** with minimum of field equipment and convenient sample size: a single operator can collect samples from 3–6 sites per day

- **Visual confirmation of the presence of gold**, focusing interest and allowing immediate follow-up panning and prospecting

- **Higher detection limit** afforded by heavy mineral concentration, as gold typically occurs as discrete, sand-sized particles

- **Avoids loss of gold in analytical preparation** (e.g. splitting and nugget effect / smearing of gold onto equipment during grinding) as the small sample size enables total digestion

# Conventional stream sediment sampling (BGS)



Stream sediment and panned concentrate sampling protocol used by the British Geological Survey for the Regional Geochemistry Project G-BASE and Tellus

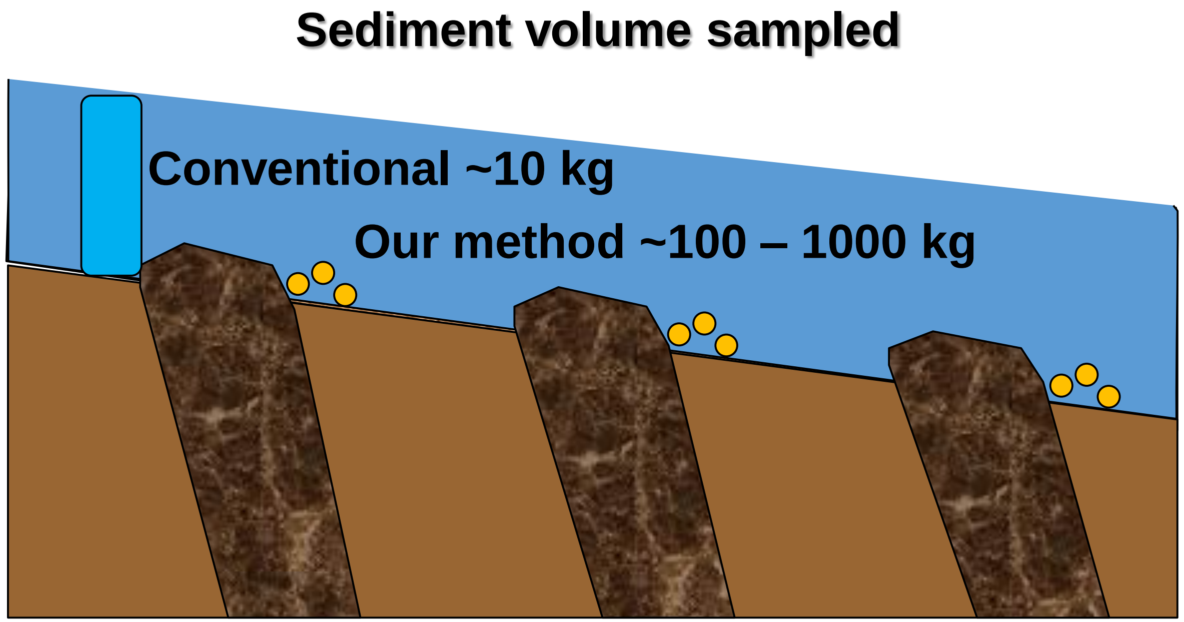
Typically 5 to 10kg of sediment is processed, usually from the top of the active profile.

Stack of 2 sieves: upper 1100 µm, lower 180 µm. Fine fraction is bagged after settling. Sediment between the sieves is panned.

**Problems –**

- Small gold particles pass through the 180 µm sieve into fines sample, not into the heavy concentrate
- Sediment volume is too small – not representative

# Our sampling method



# Sampling methodologies: gold *versus* heavy minerals

**For heavy mineral studies –**

- Sample active stream sediment that is representative of the river catchment area or till stratigraphy (as opposed to targeted sampling of gold-rich material)
- Do not use sediment from which 'fines' have been removed – e.g. <180 μm as per BGS Tellus protocol – this can bias the proportions of heavy minerals in sample
- During panning, take care to not lose heavy minerals, yet remove as much as possible of light minerals (takes more time than gold separation)
- Remove obvious contaminants e.g. lead shot, wire etc.
- At the site, transfer the heavy mineral concentrate (HMC) into a self-sealing plastic bag, excluding air. When back in the laboratory, dry by opening bags in air or in warm oven (40-50°C).
- Optional to sieve HMC to remove coarse particles e.g. >1mm. Option to remove magnetite using a hand-held magnet (but this is unwise: case study).

# HMC sampling method (video)

Sluicing & panning active river sediment to obtain a heavy mineral concentrate

# HMC sampling from a small upland stream

Before

After

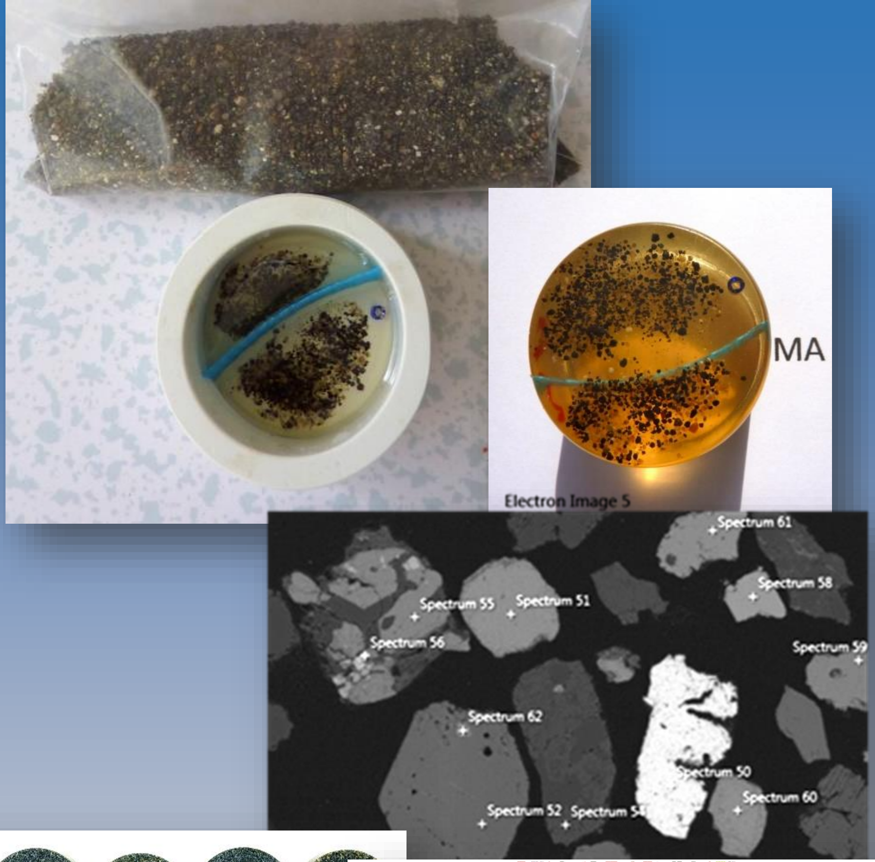
# HMC analysis methodologies

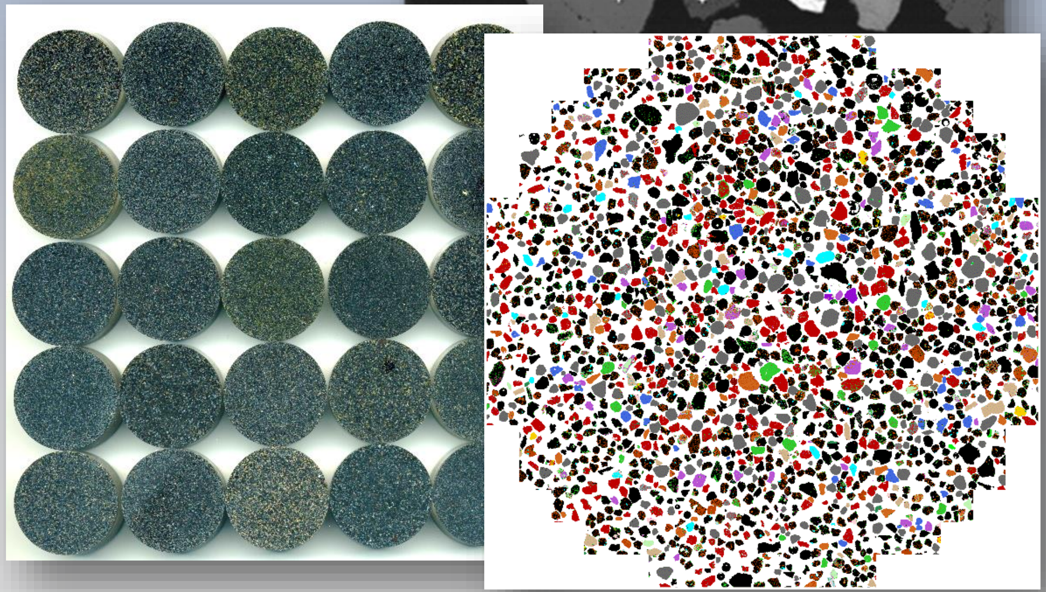
**Qualitative**

- Visual inspection – can always recognize gold, with experience can roughly estimate % major minerals
- Embed HMC sample in resin, then grind & polish or thin section for optical microscopy and/or SEM

**Quantitative**

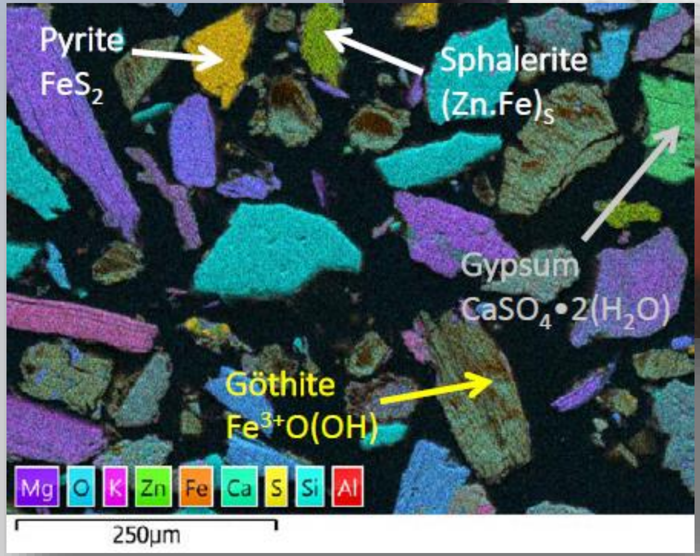
- XRF analyses – of raw sample (poor data) or powdered sample (good data, but destructive)
- XRD analyses of powdered sample
- QEMSCAN® or similar SEM analyses of resin-embedded sample. Repeated re-grinding enables more data from a single mount.



QEMSCAN® = Quantitative Evaluation of Minerals using a Scanning Electron Microscope

# HMC analysis methodologies – more next week




**In webinar 3:**

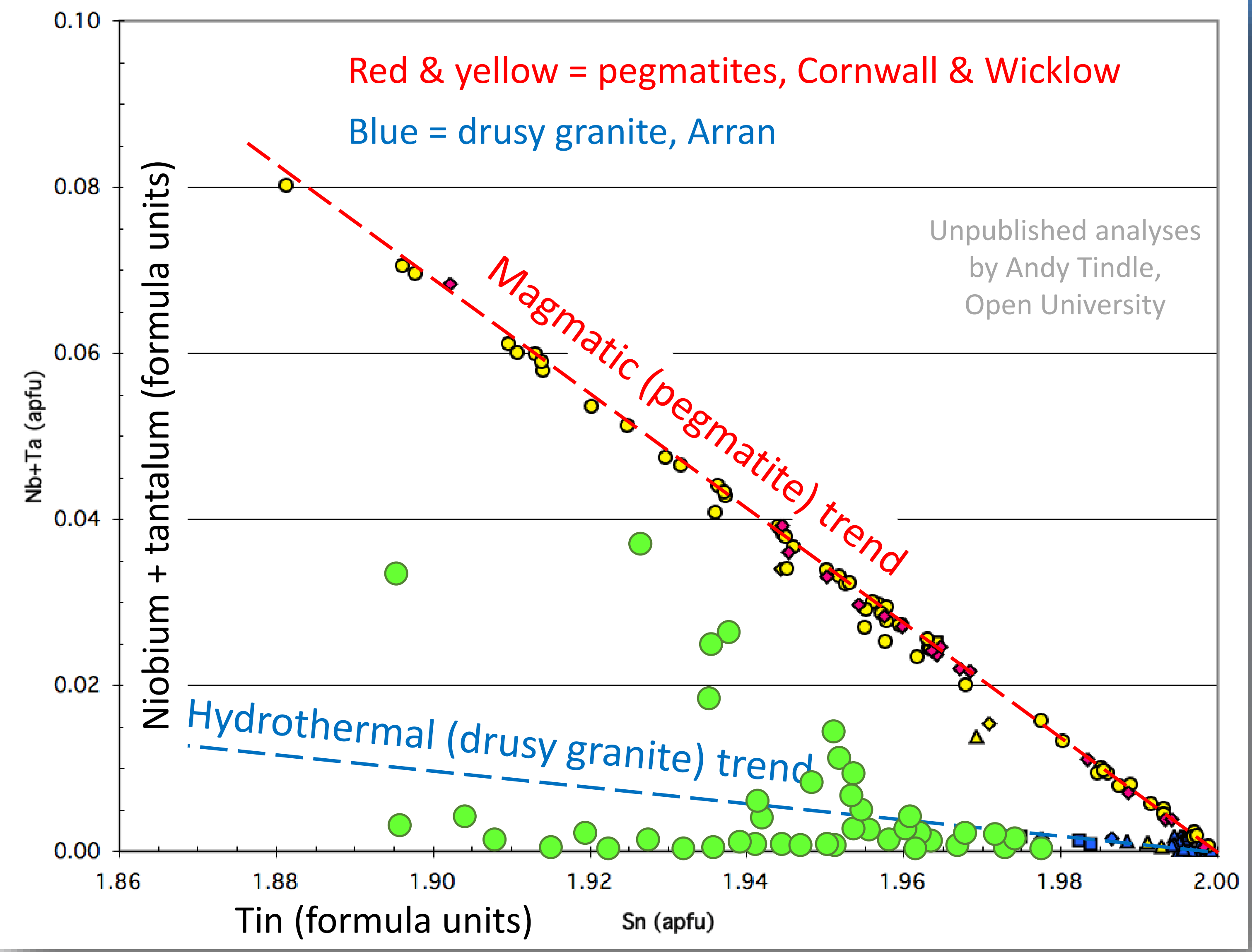
Marja Lehtonen and Yann Lahaye (GTK, Finland)

**Indicator minerals analytical techniques: identification, isotope and trace element analysis**

Marja will focus on indicator mineral projects they have carried out in the GTK Research Lab, and on the equipment and techniques used.

Yann will describe the lab's LA-ICP-MS equipment and examples of projects completed.

# Heavy mineral chemistry may indicate mineralization style




- Determined by EMPA, minor element compositions of some heavy minerals can indicate specific styles of mineralization
- For example: cassiterite in **pegmatites** typically contains Nb and Ta substituting for Sn, whereas in **drusy granite** cassiterite has less Nb and Ta but more Fe and other elements
- Mournes HMC cassiterites straddle the fields of pegmatite and drusy granite, suggesting both styles occur in bedrock but predominantly hydrothermal

# **3. SE Ireland case study:** integration of data from sediment fines, heavy mineral concentrates, and gold particles

# Rationale for using multiple methods in SE Ireland

## Sediment fines
collected by GSI in 1980s and re-analysed as part of Tellus programme

### Purposes:

1. Reveal metal enrichments associated with clay minerals;
2. Provide geographical constraints for our labour-intensive, targeted gold grain studies

### Issues:

Metal loadings may be affected by weathering or anthropogenic activity

## Heavy mineral conc.
collected by us 2000-2010

### Purposes:

1. Spatial distributions constrain the directions and extents of glacial transport;
2. Aids interpretations of placer-lode relationships from gold particle studies

### Issues:

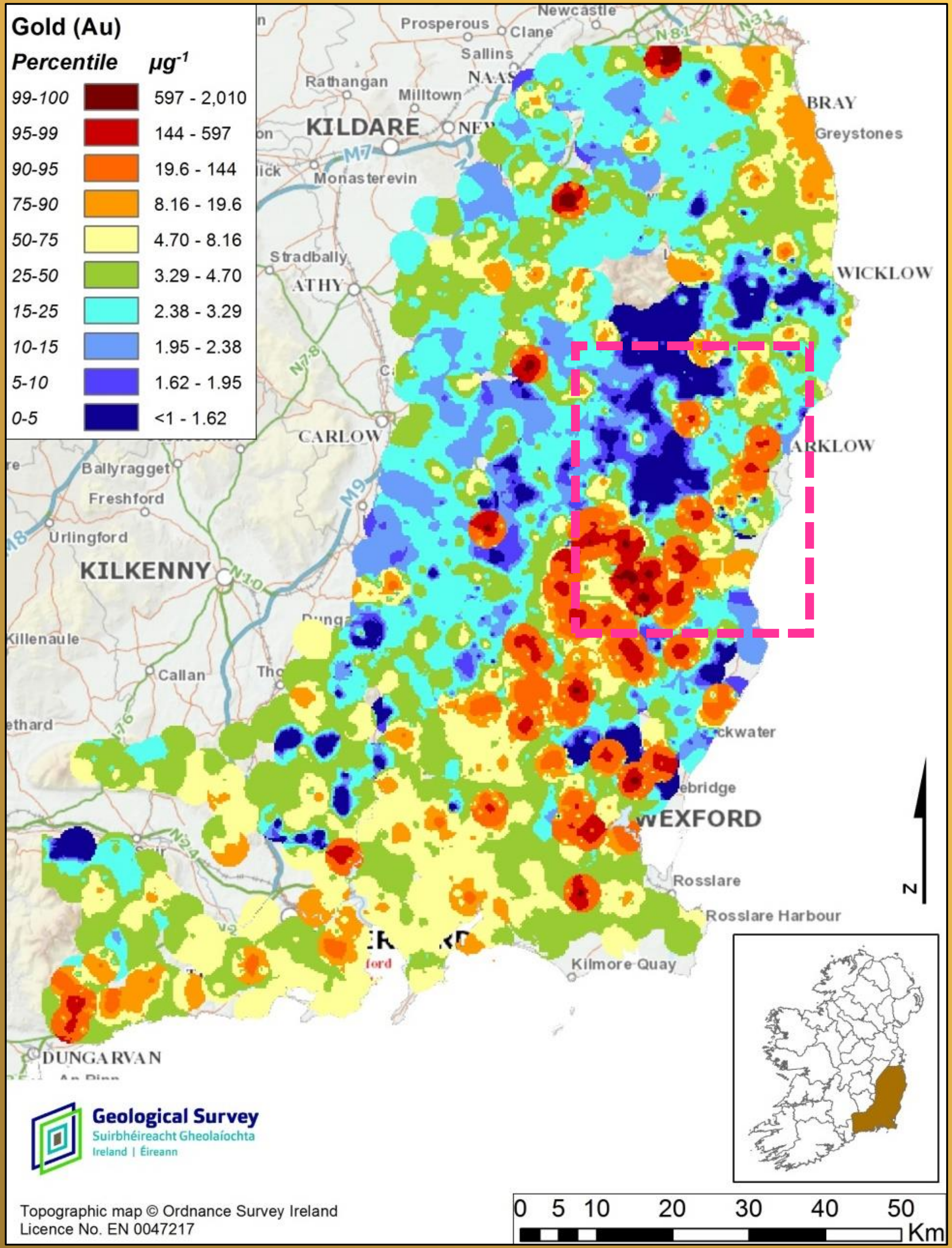
Resistate heavy minerals from distant sources co-collected with ‘local’ gold

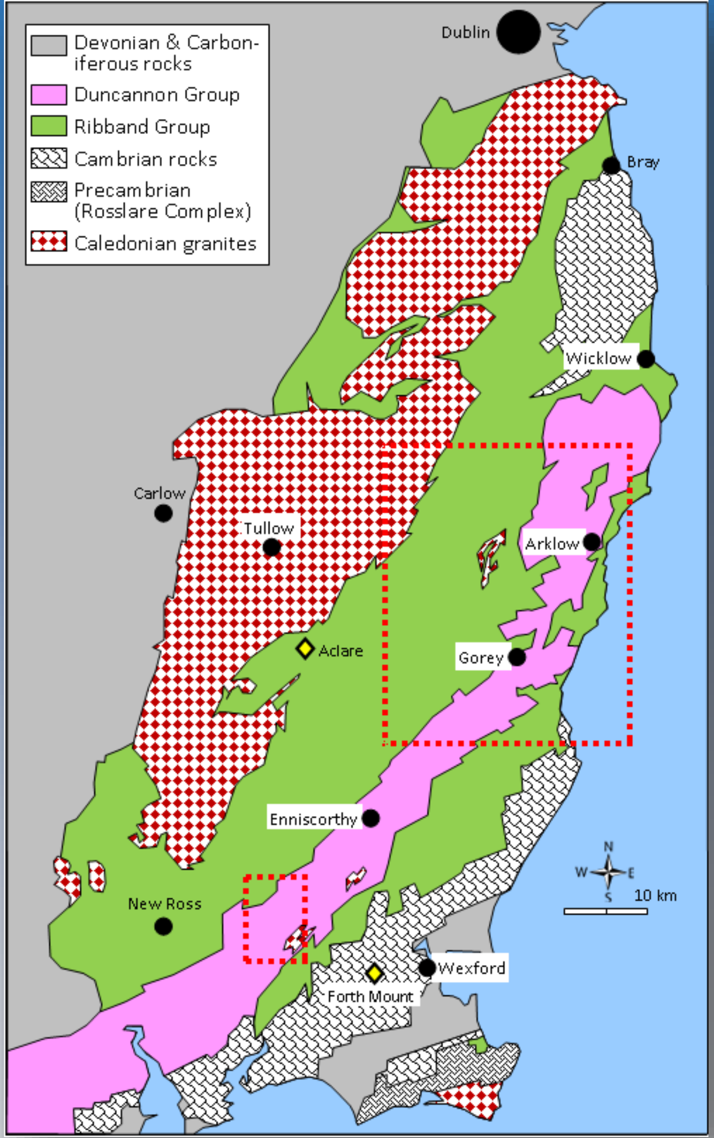
## Gold particles
collected by us 2000-2010

### Purposes:

1. Abundance and alloy compositions provide evidence for location and variability of bedrock mineralization;
2. Mineral inclusions indicative of hypogene mineralogy;
3. These highlight specific gold-element associations useful for interpretation of ‘fines’ geochemical dataset

# Au (ppb) in sediment fines: GSI Tellus analyses

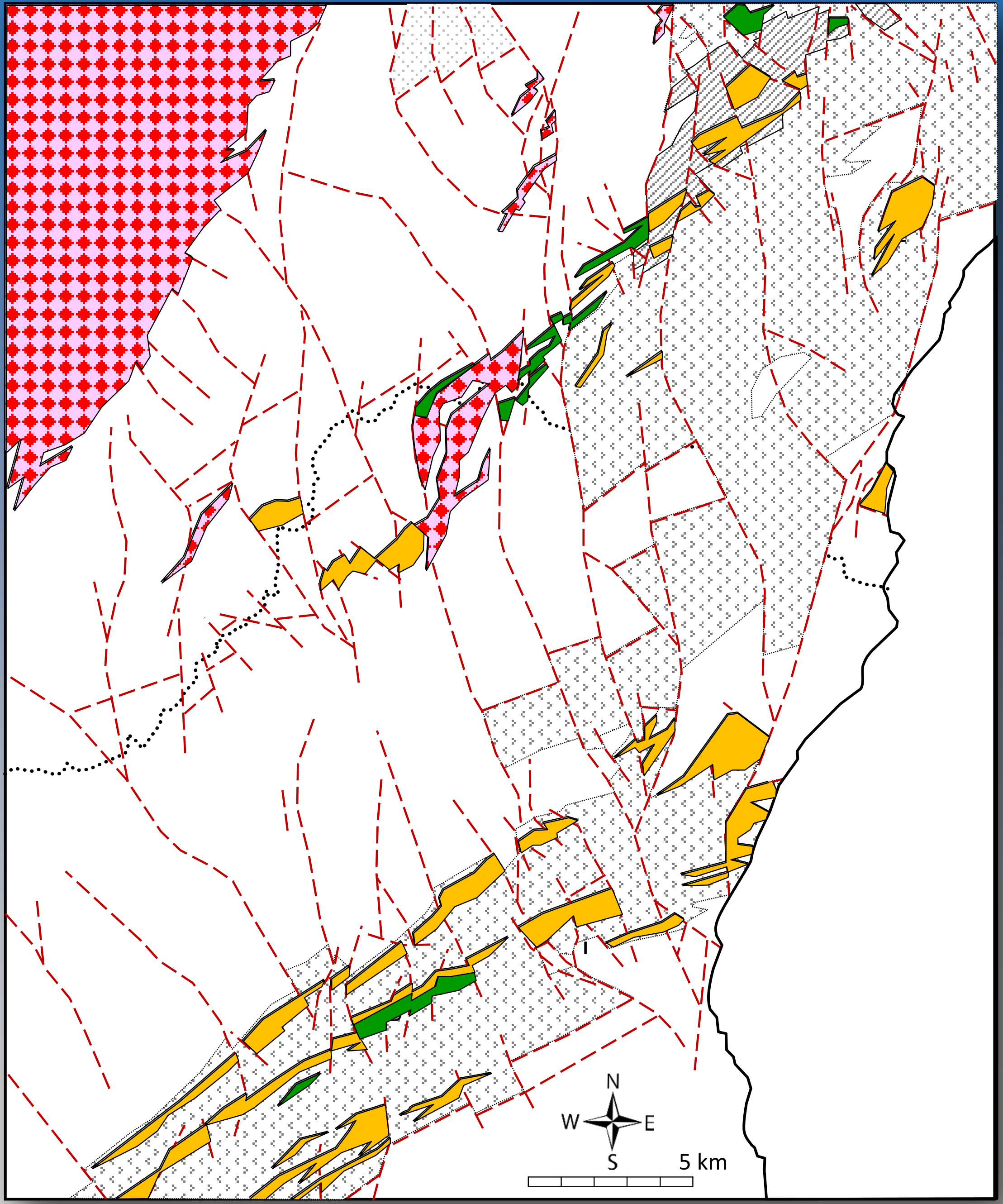



Bedrock geology our study area

Moles & Chapman (2019) Integration of detrital gold microchemistry, heavy mineral distribution and sediment geochemistry to clarify regional metallogeny in glaciated terrains: application in the Caledonides of southeast Ireland. *Economic Geology* **114**, 207-232.

# Geology, mineralization

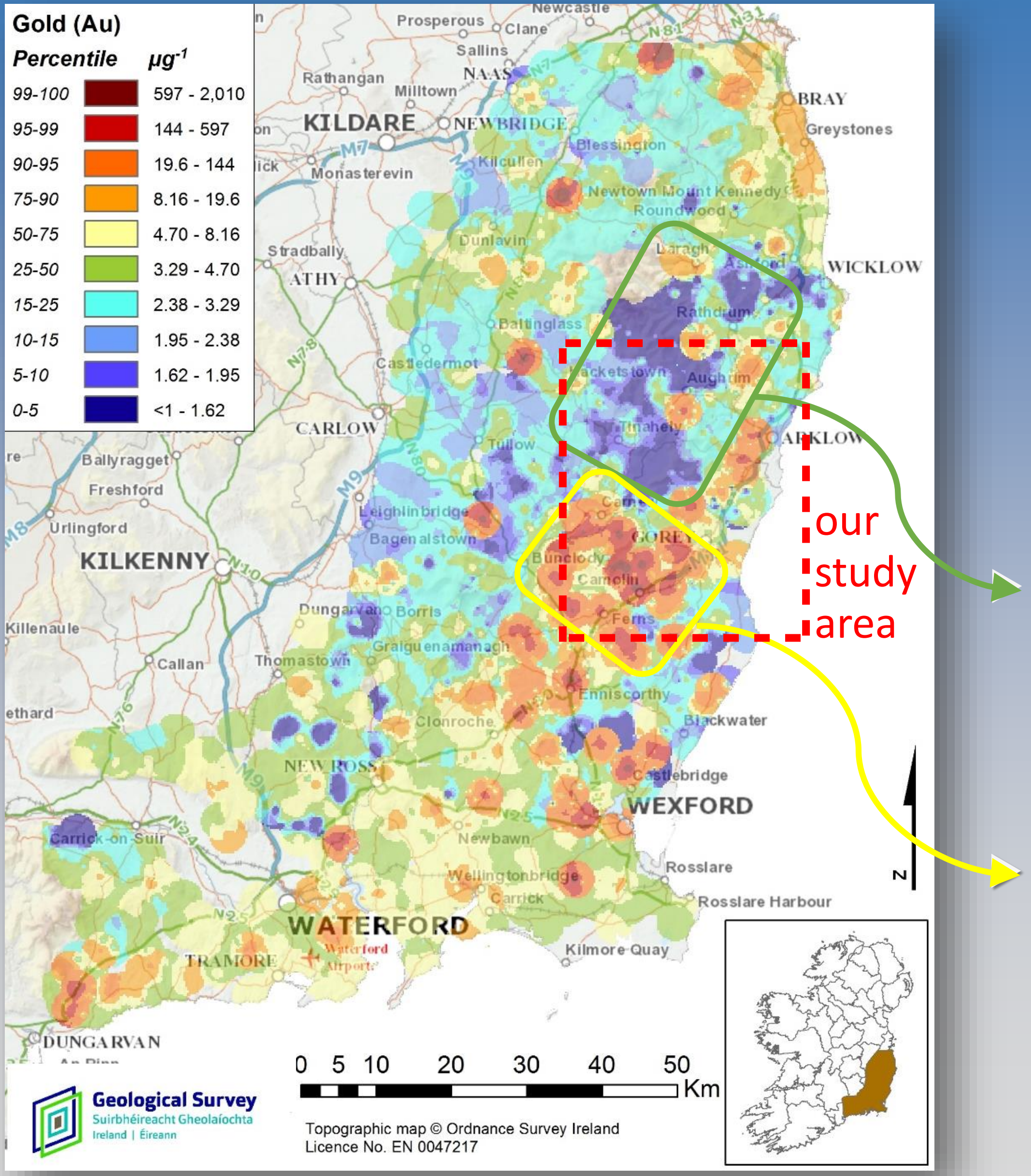



- Duncannon Group
- Avoca Volc. Group: 464 ± 2.6 Ma *
- Ribband Group
- Granite: Croghan 456 ± 2.4 Ma *
- Felsic intrusive
- Mafic intrusive

- Avoca VHMS Cu, Kilmacoo Au
- Iron formation
- Stratabound Fe-As-S-Au
- Quartz veins
- W-Sn greisen
- W-rich river sediment
- Alluvial gold reported

- Mainly phyllites and chlorite schists, with fault-repeated belts of mafic & felsic volcanics
- Syn-sedimentary VMS and ironstone, stratabound Fe-As-S-Au enrichment
- Syn-orogenic granites with W-Sn enrichment in aureoles
- Alluvial gold occurrences previously reported in the north (Wicklow), but not in the south (Wexford)

# Southeast Ireland sediment fines Au




Fine fraction stream sediment samples collected in the 1980s at a density ~1 per 4 km$^2$

High precision analyses by GSI published in 2016

About 5% show elevated Au, range 0.1 to 1.5 ppm

In the Avoca – Goldmines River area of known gold mineralization, Au values >0.1 ppm occur in only one fines sample. No gold found in sediment at most localities of historical gold winning.

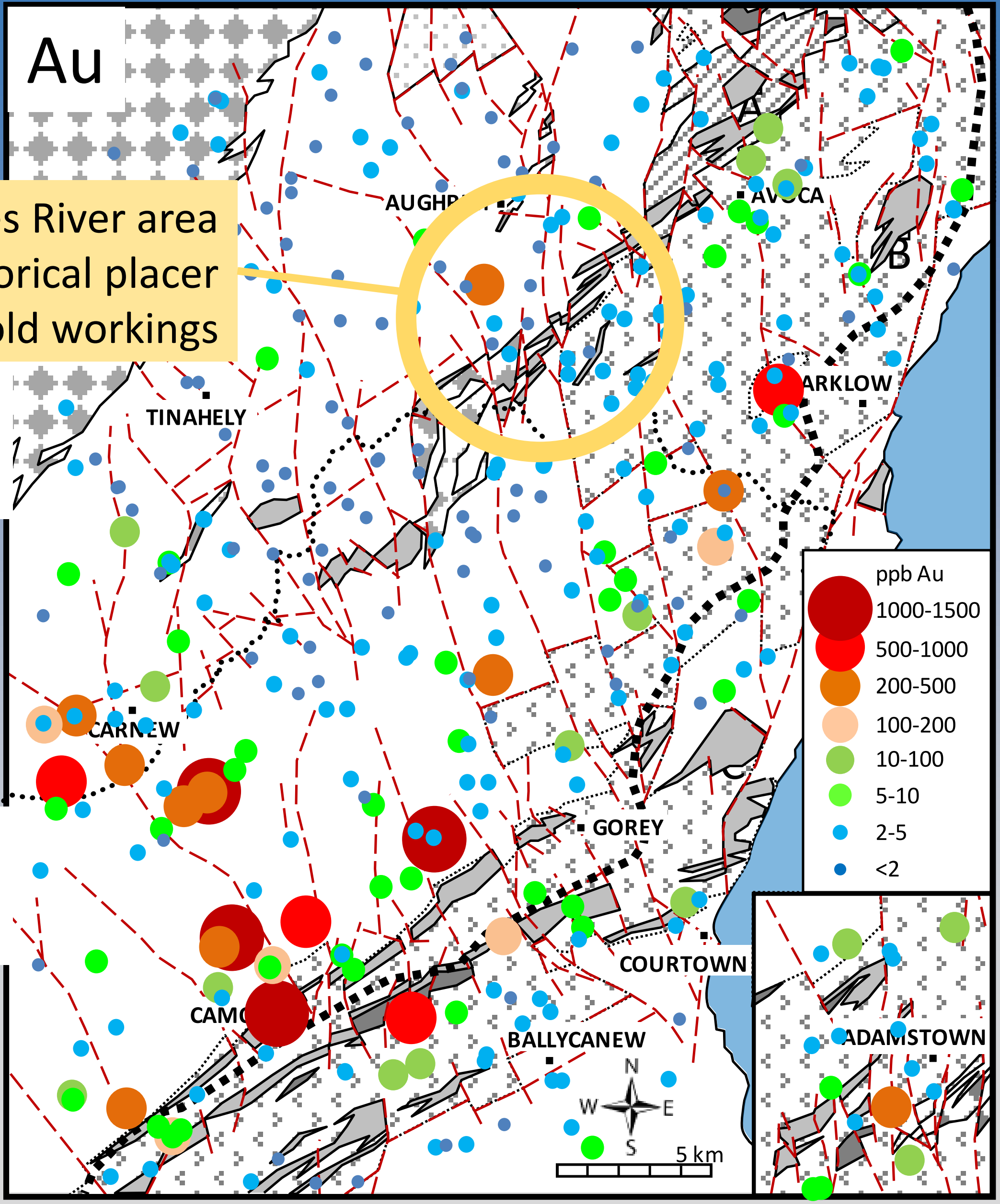
Samples with >0.5 ppm Au mostly located in north Wexford in a NW-SE trending belt perpendicular to the NNE-SSW 'Caledonian' trend.

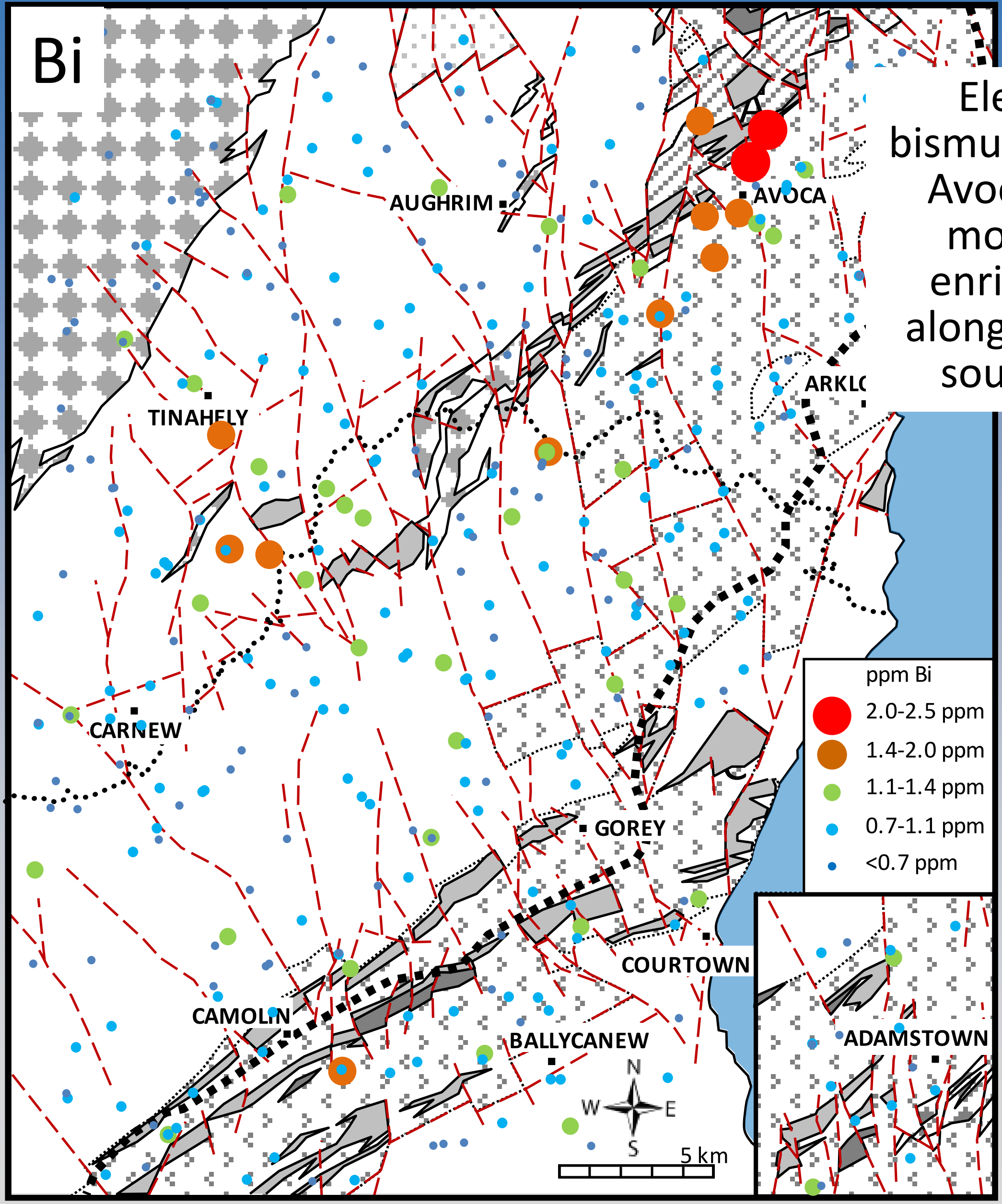
# Fine fraction sediment geochemistry (Tellus data) – 1 of 3

Goldmines River area of historical placer gold workings

generally low Au in north

generally high Au in south

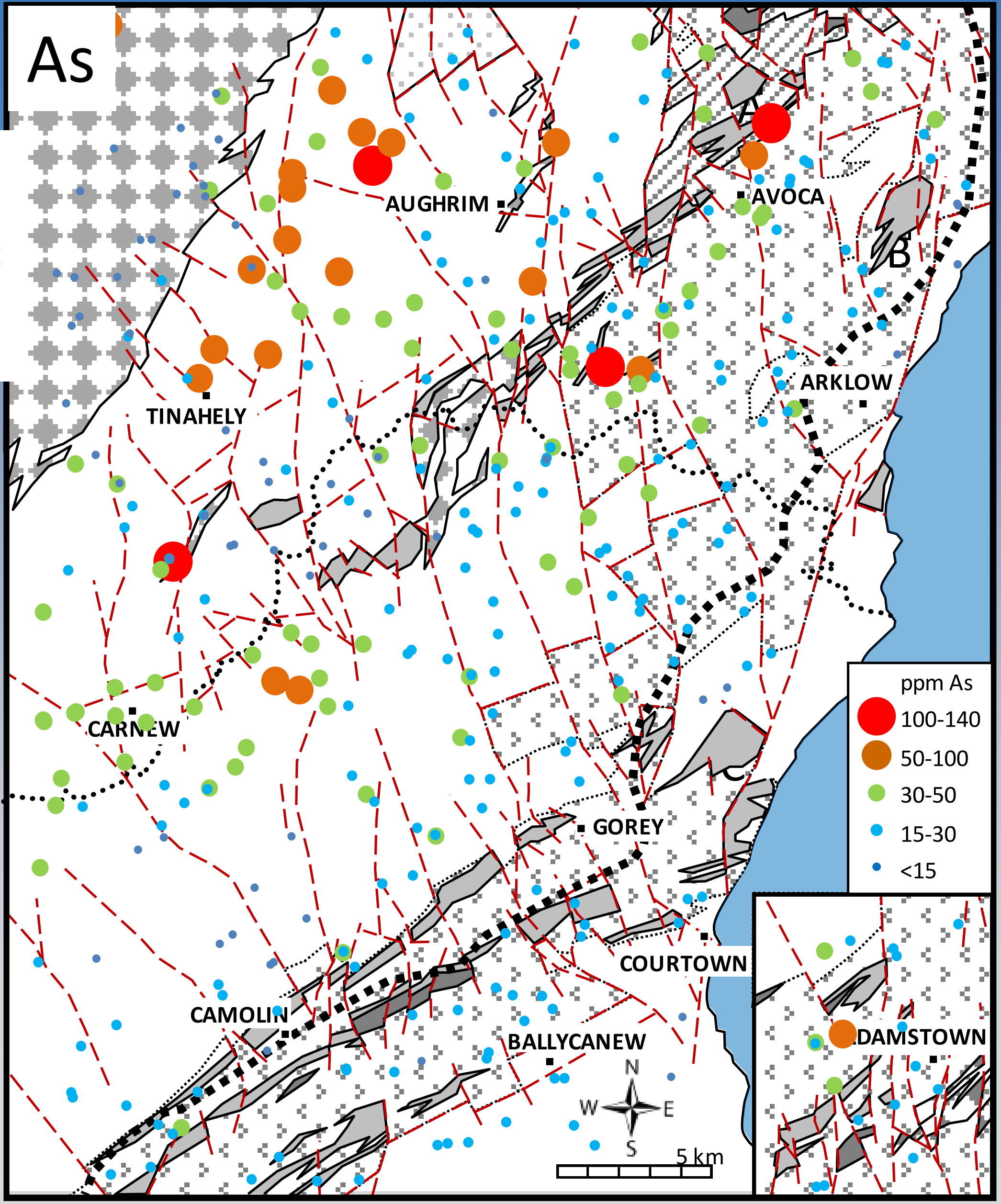


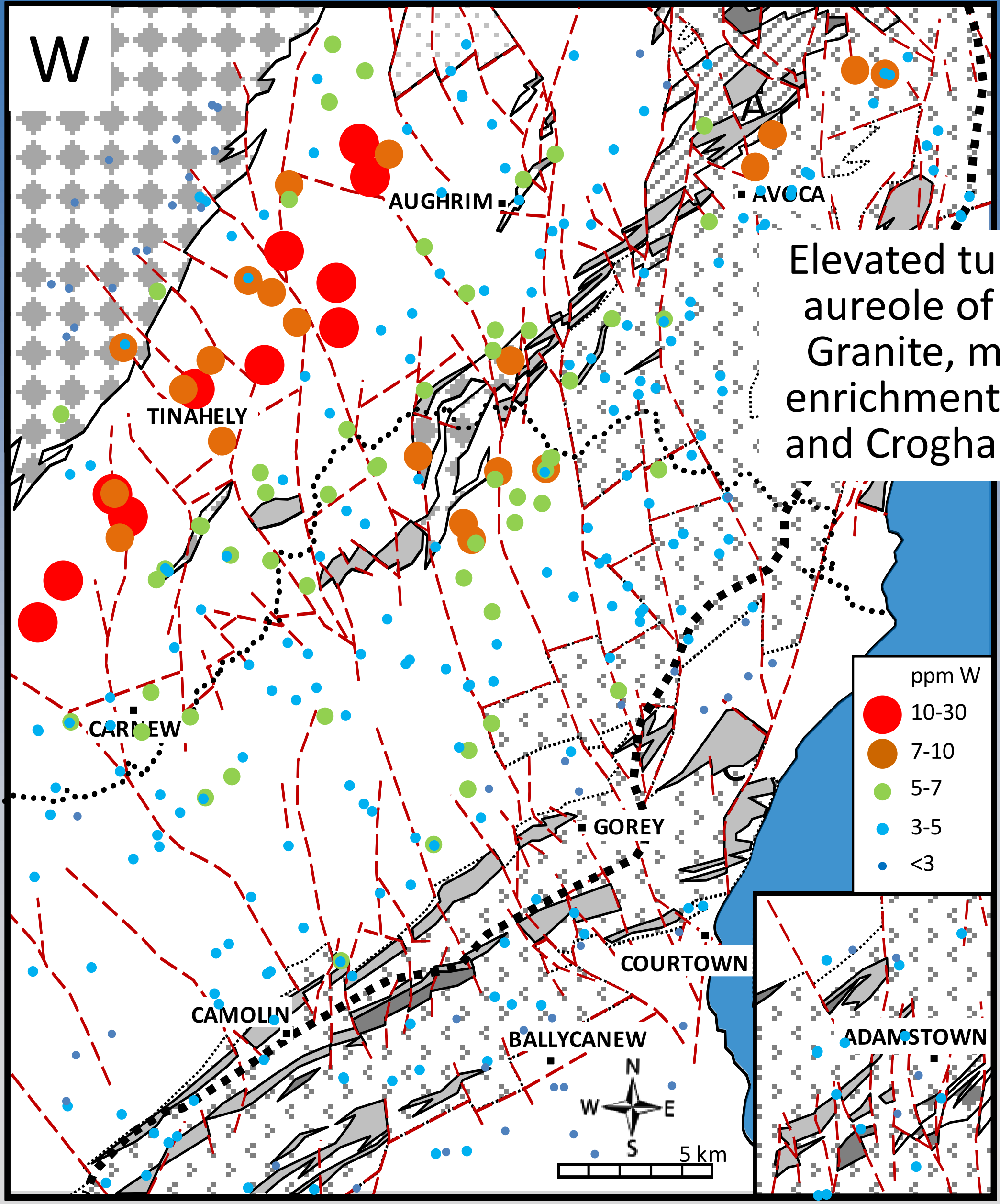




Elevated bismuth around Avoca VMS; moderate enrichment along strike to southwest

# Fine fraction sediment geochemistry (Tellus data) – 2 of 3

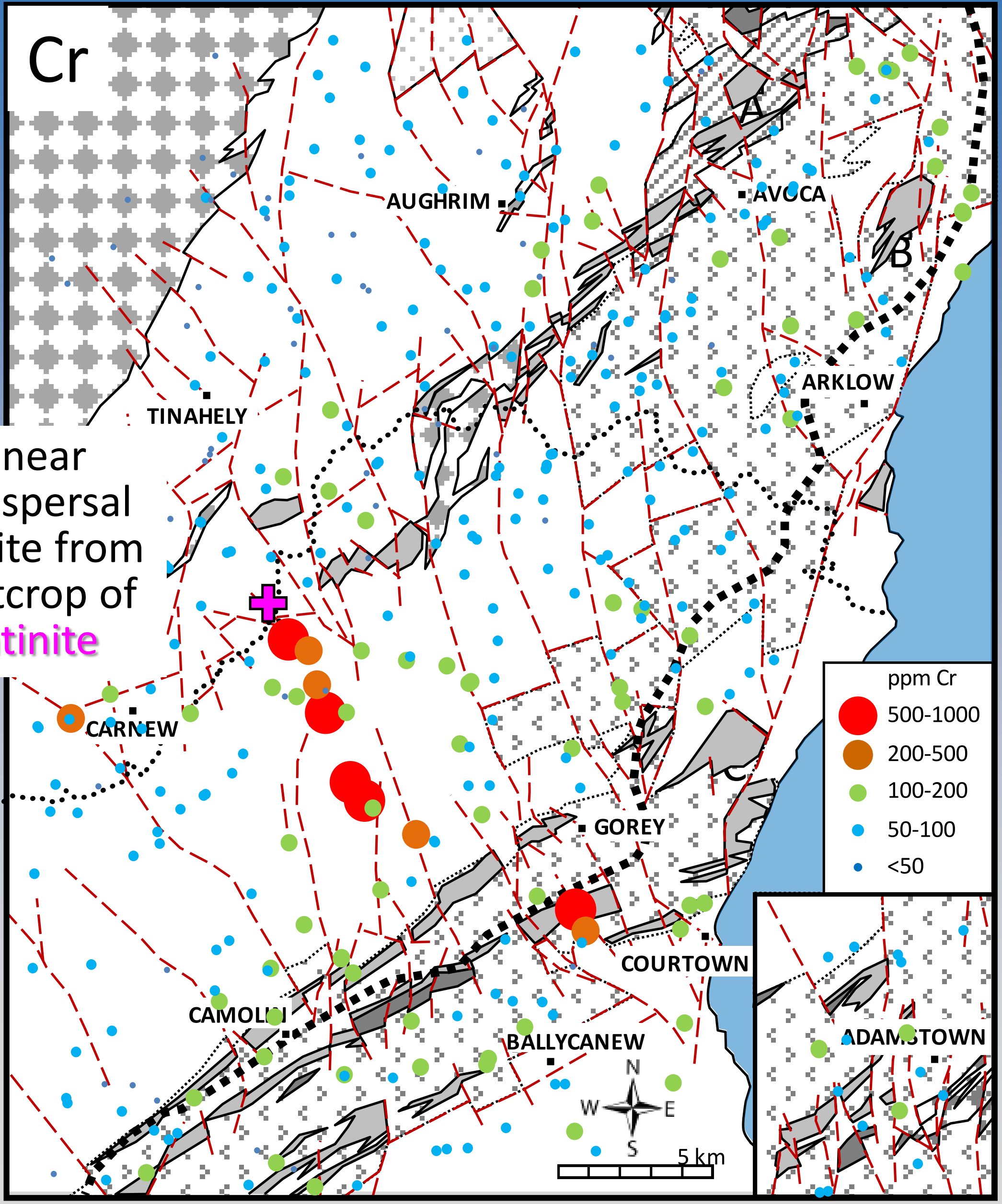
Elevated arsenic in north: several clusters



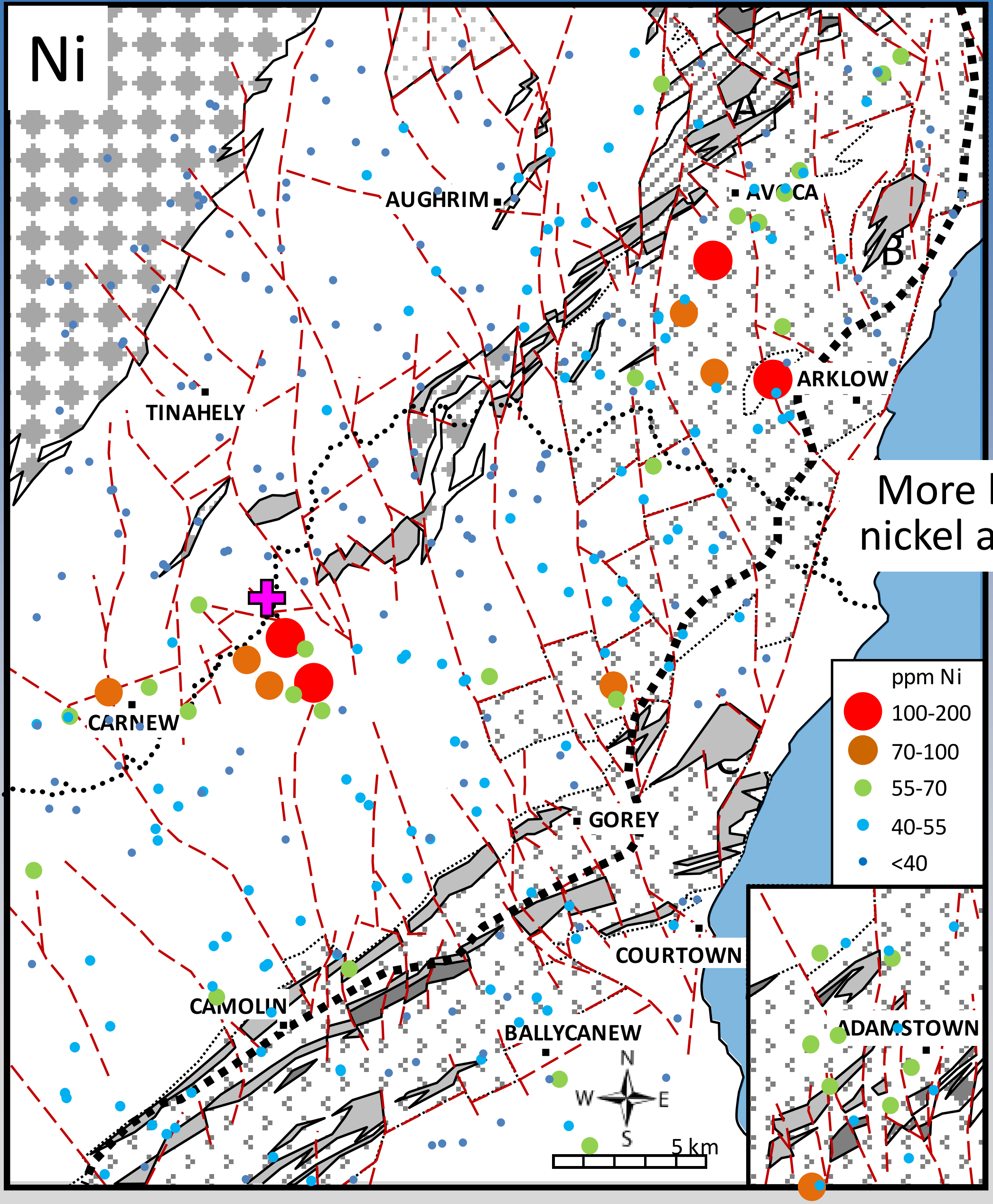




Elevated tungsten in aureole of Leinster Granite, moderate enrichment at Avoca and Croghan Granite

# Fine fraction sediment geochemistry (Tellus data) – 3 of 3

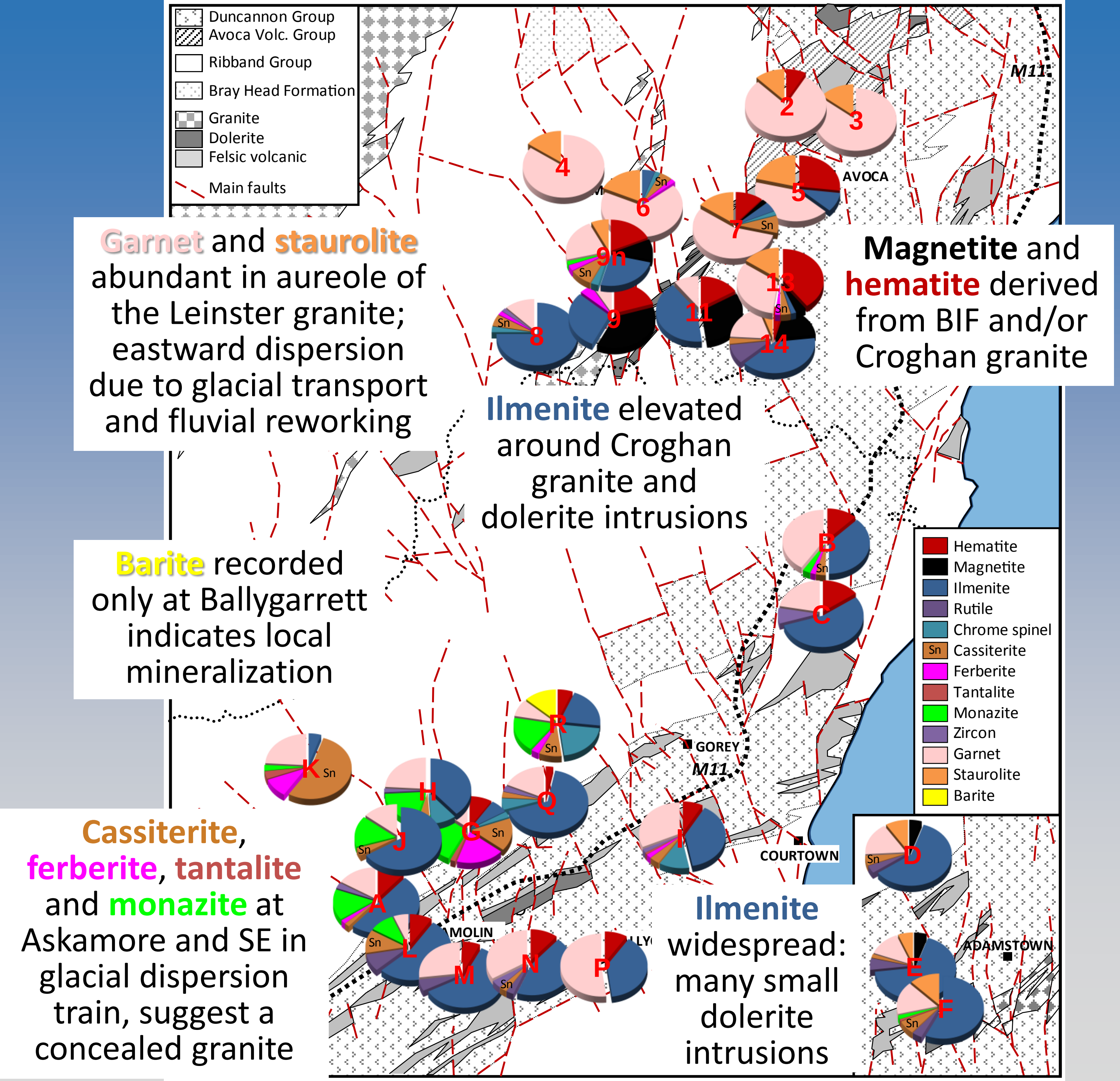



Curvilinear glacial dispersal of chromite from small outcrop of serpentinite



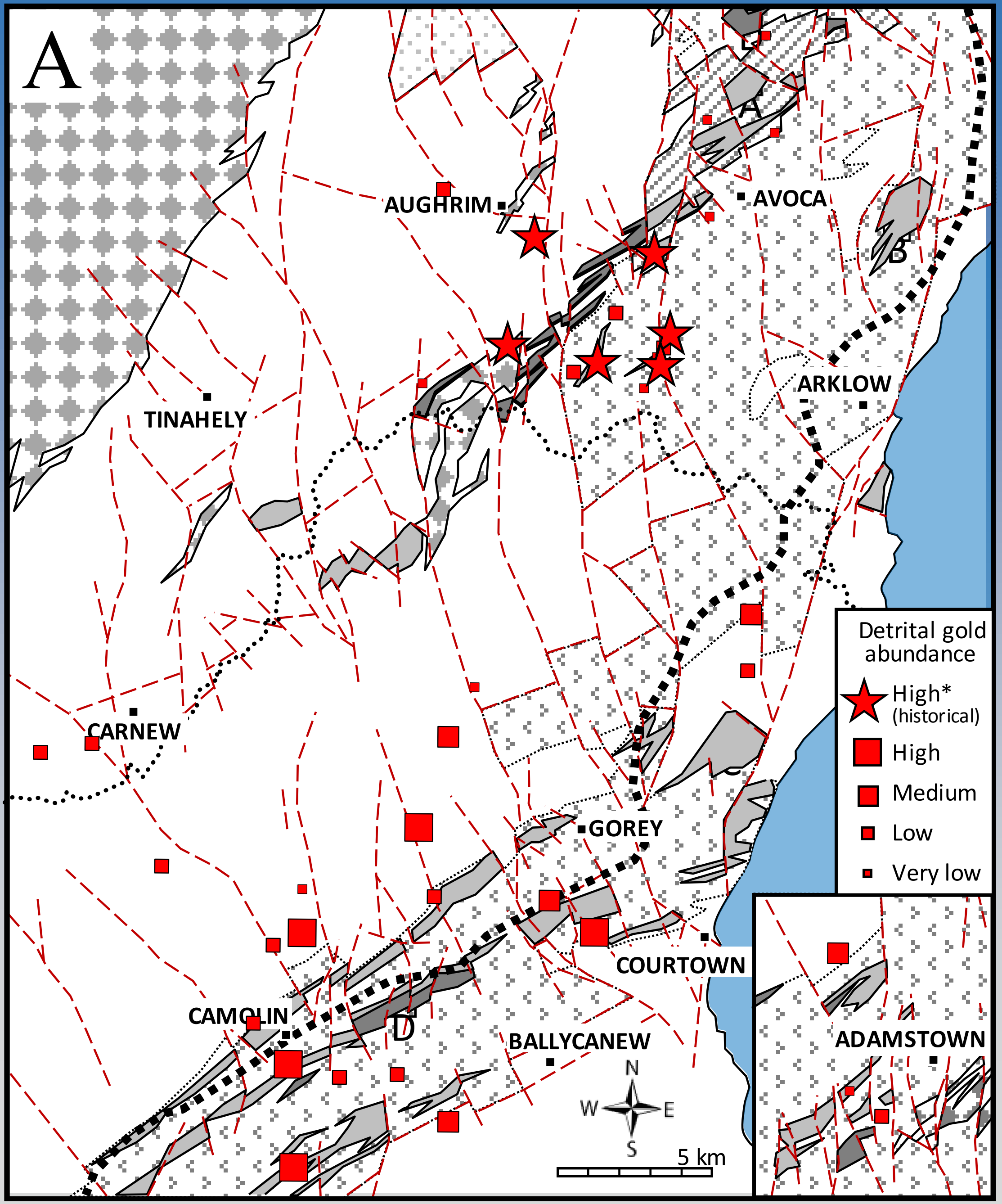

More localised nickel anomalies

# Our data: Heavy mineral proportions

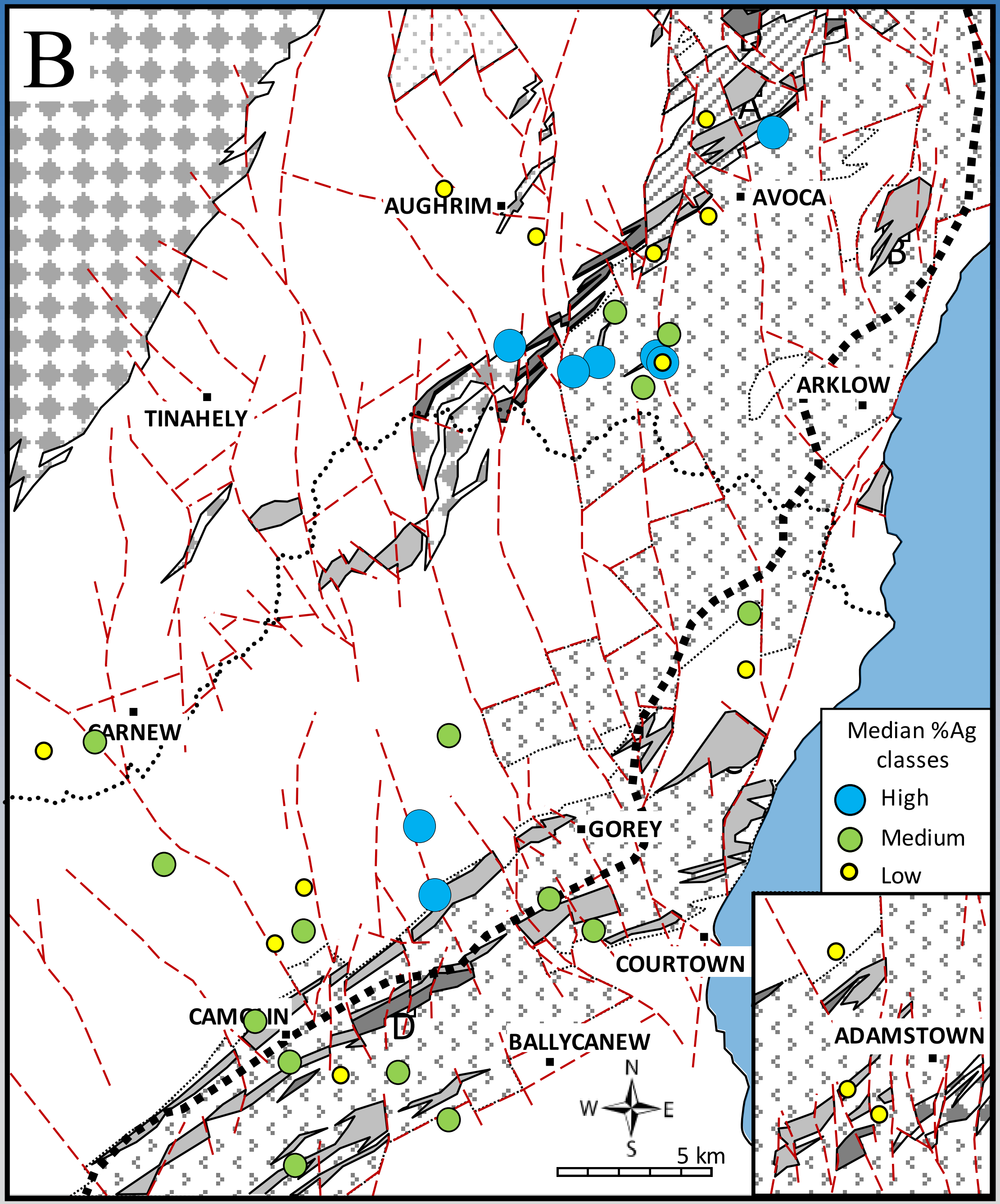



- Mineralogical diversity due to a variety of local overprints of a ubiquitous garnet + staurolite signature.
- Minerals associated with 'point sources', notably monazite, cassiterite, ferberite, magnetite and chrome spinel, have been dispersed up to several kilometres eastwards of bedrock sources.
- This transport distance and direction accords with the dispersion shown by the fine-sediment geochemistry for W and Cr from their parent rocks.

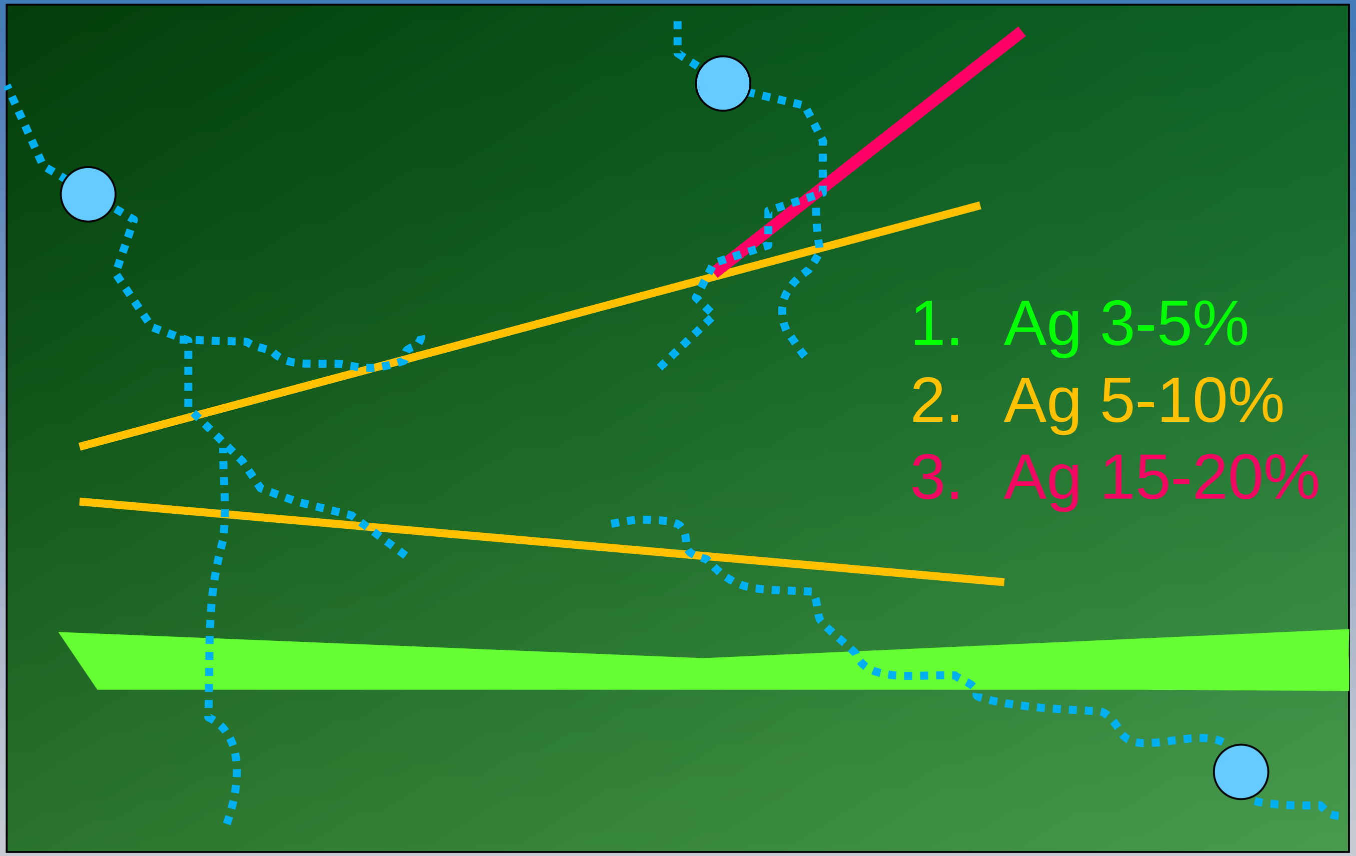
# Detrital gold abundance

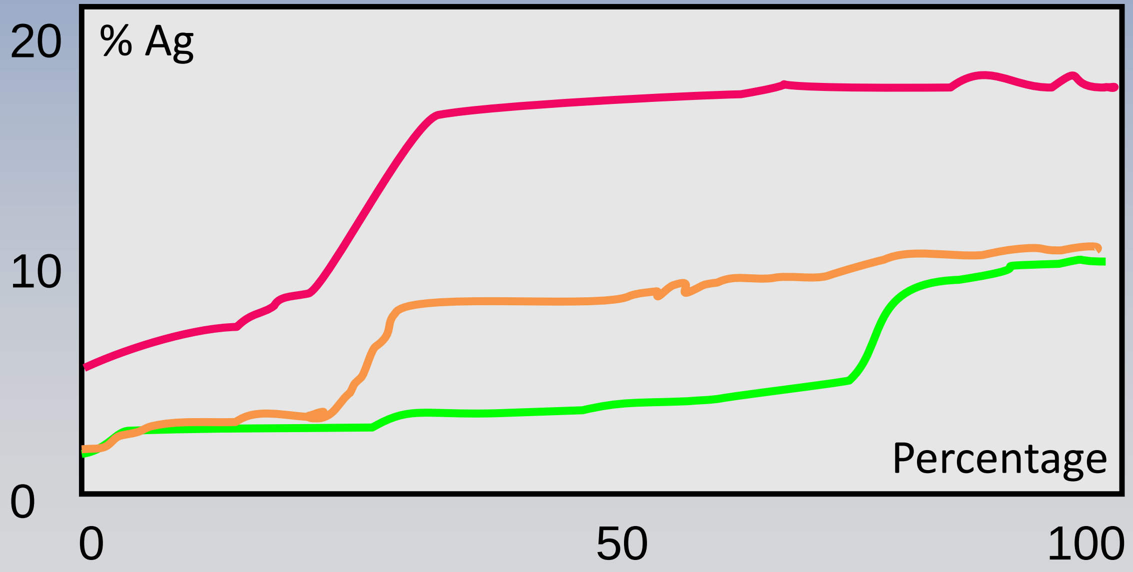



# Sample average Ag content

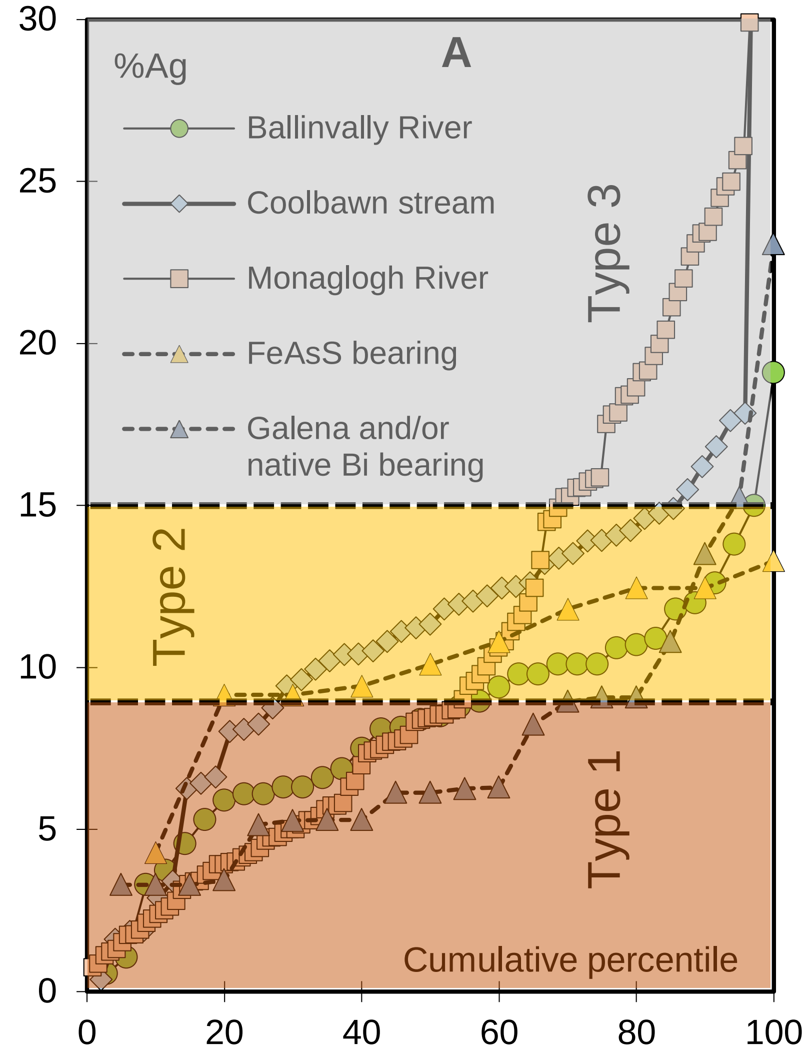


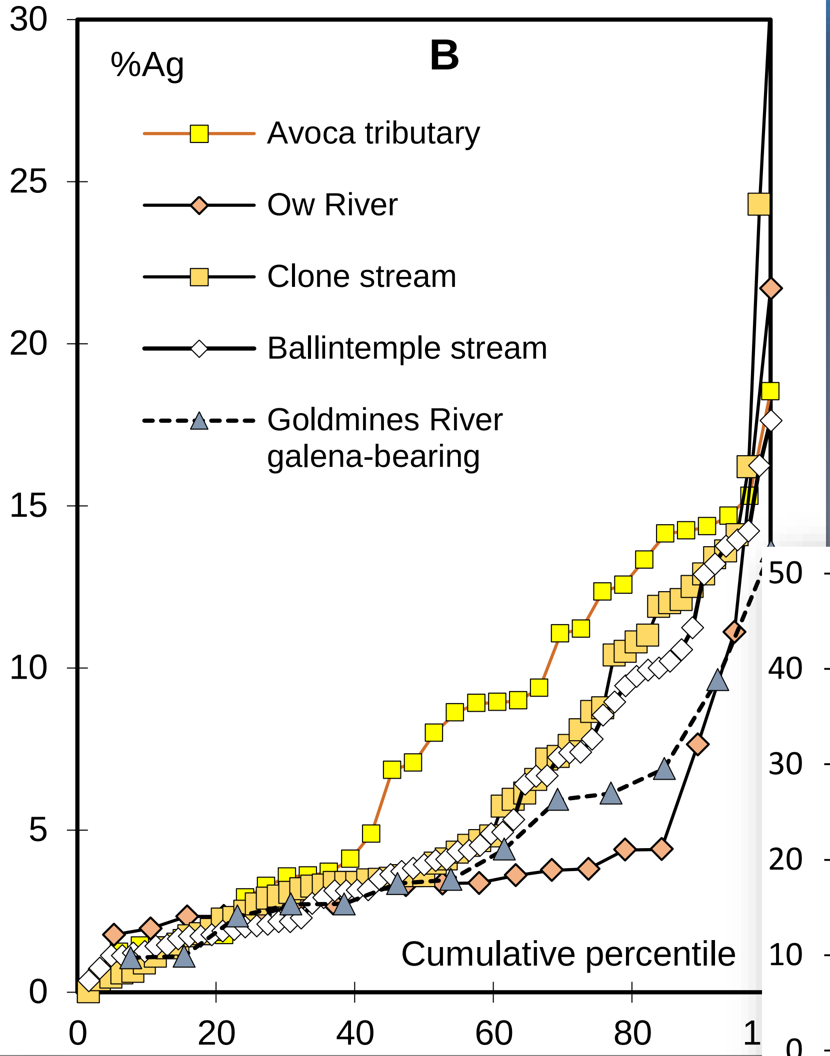
# Generation of complex signatures



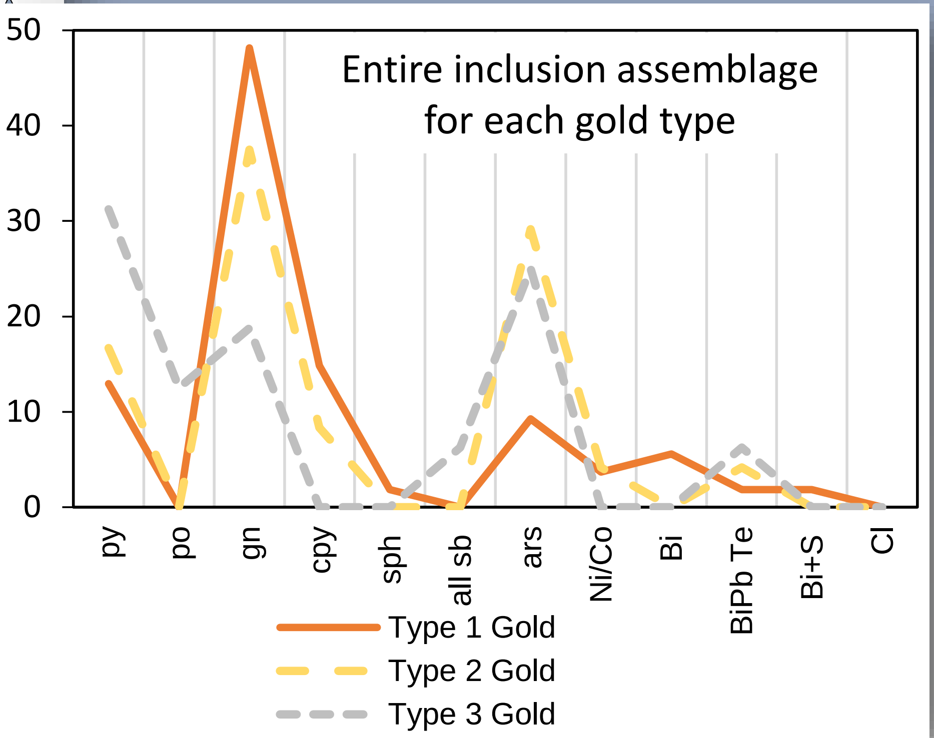



# Cumulative %Ag charts, type classification, inclusion assemblages



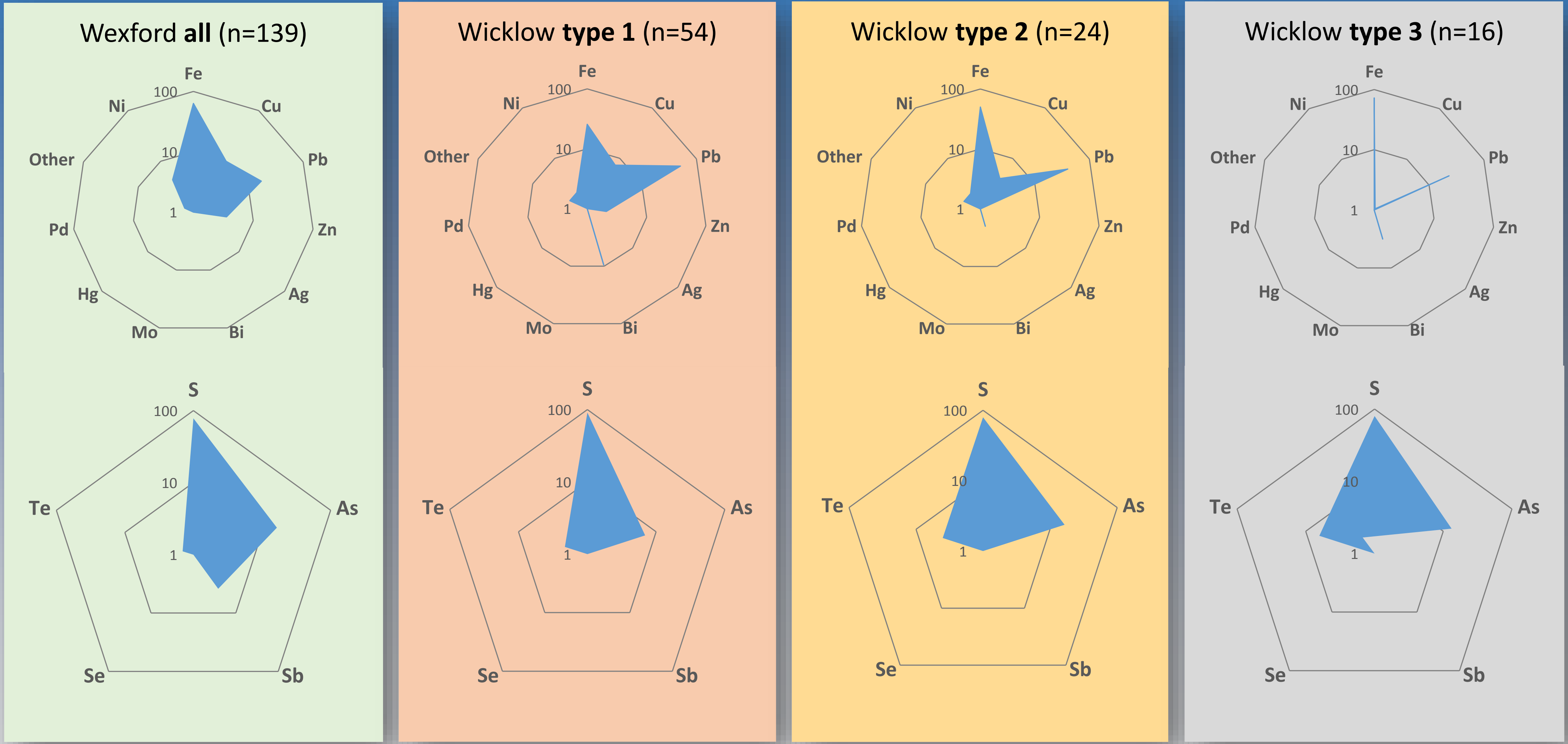




| Type | 1 | 2 | 3 |
|---|---|---|---|
| %Ag range in alloy | 0 – 9 | 9 – 15 | >15 |
| Defining inclusion–mineralogy | Galena ± native bismuth | galena, arsenopyrite | arsenopyrite |




We have two independent sources of information that permit identification of 3 signatures. Each occurs in varying proportions in the different drainages – as in the hypothetical example.

# Cumulative %Ag charts, type classification, inclusion assemblages

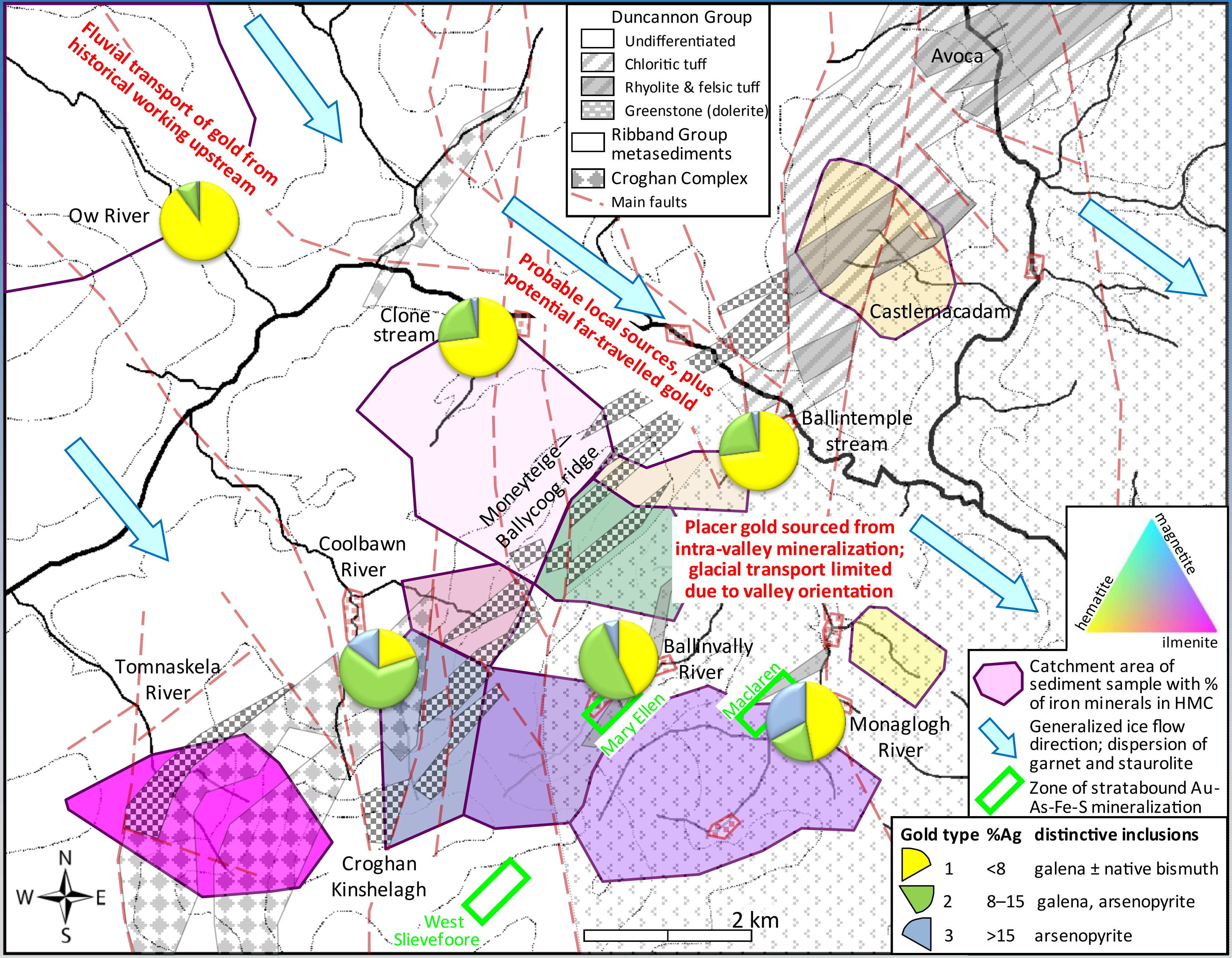



**If the types represent a time sequence, the mineralizing fluid appears to have evolved progressively:**

**Copper** is highest in Wexford and in Wicklow type 1, appears to decrease in type 2 and is absent in type 3.

**Native bismuth** inclusions are present in type 1, then fTe increases with **Pb-Bi tellurides** in types 2 and 3.

# Goldmines River area: HMC Fe-Ti oxide mineralogy and gold types

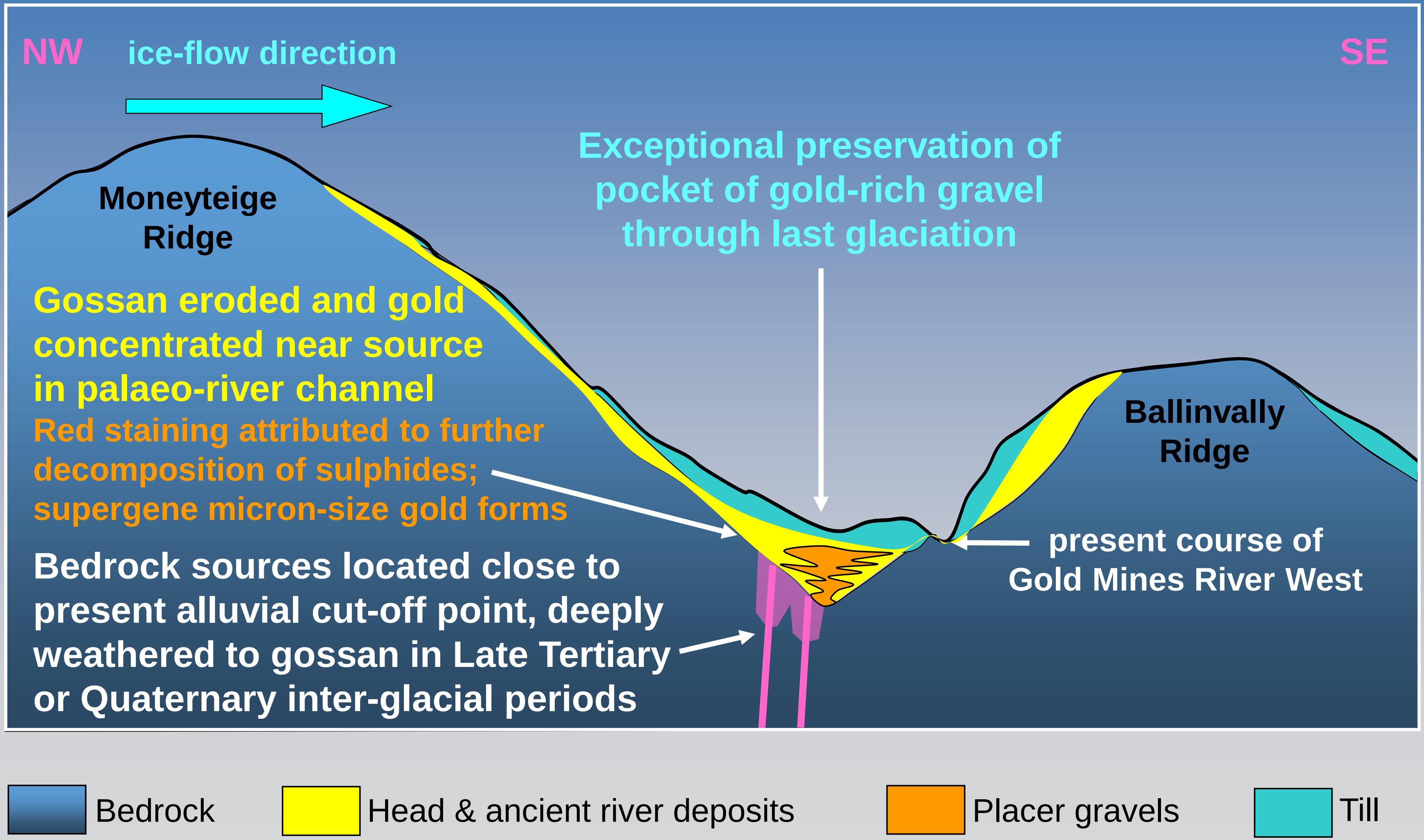



Catchment areas colour-coded according to proportions of hematite, magnetite, and ilmenite. Opacity is in proportion to abundance. Pie charts show proportions of gold types 1 to 3 in each main area.

## Conclusions

- Diverse heavy mineral assemblages in adjacent catchments >> dominantly **local derivation of sediment**, rather than long-distance glacial transport.
- Ballinvally and Monaglogh River placer occurrences are adjacent to zones of Au-As-Fe-S mineralization, but **the proportions of gold types are strikingly different**, indicating separate sources and styles of mineralization.

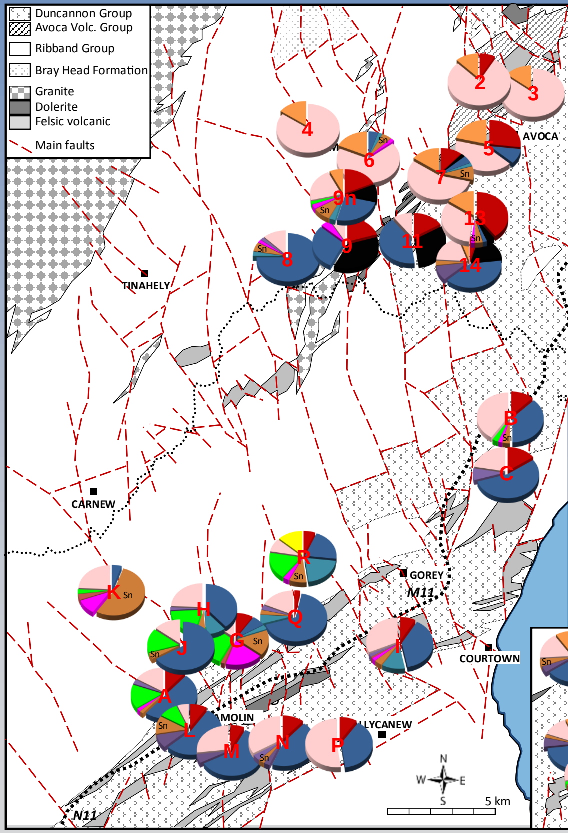
# Proposed model for ‘Red Hole’ gold placer



# SE Ireland case study conclusions

Characterisation of >2000 gold particles and HMC from 40 localities provided a clear indication of proximity of gold to source, and identified gold derived from different episodes of mineralization.

- **In the north** (Wicklow), the historical placer mining district yielded gold with distinctive Pb-Bi-As inclusions indicating a magmatic association. Highest gold abundances and particle sizes occur where magmatic fluids interacted with pre-existing regional stratabound Au-As-S mineralization.
- Here, we infer minimal transport of gold based on (i) the large particle size, (ii) locally high gold abundance, and (iii) the distinctive and geographically constrained HMC signatures. The placers represent efficient accumulation and preservation of detrital gold derived from several discrete sources.
- **In the south** (Wexford), proximal Au mineralization is inferred at two localities that also have distinct HMC mineralogy. Elsewhere, low abundances of gold, and similarity of HMC mineralogies irrespective of bedrock lithology, suggest glacial-fluvial transport from multiple occurrences of localised Fe-As-S mineralization.



# Integrated gold–HMC–fines studies: generic conclusions

**All three approaches are mutually supportive:**

- **Sediment fines analyses**
  - reveal prospective formations, igneous or structural features
  - highlight areas for labour-intensive targeted gold grain studies
- **Microchemical characterization of detrital gold**
  - establish genetic links with types of hypogene mineralization known or inferred in the region
  - identify specific gold-element associations useful for interpretation of geochemical datasets
- **Heavy mineral quantification / spatial distribution**
  - constrain directions and extents of glacial transport
  - distinctive minerals help locate proximal bedrock mineralization

- It is essential to establish **regional signatures** of both HMC and gold particles, to be able to discern **local variation** associated with proximal and/or distinctive styles of mineralization.
- **Differences in spatial distributions** of fine-fraction geochemical anomalies (e.g. Au, As) and abundances of gold particles or other indicator minerals **provide useful information** on the characteristics of bedrock mineralization and surficial weathering and transportation.

Moles & Chapman (2019) Economic Geology 114 (2), 207-232